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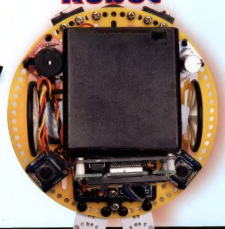

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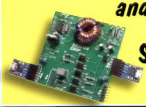

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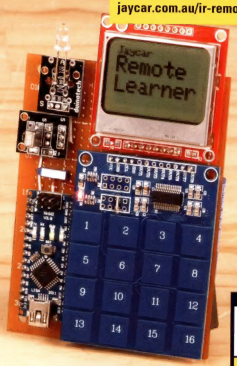

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Atmel and Microchip are now one and we're starting to see new devices which feature the best of both families. Here we look at the ATtiny816 and to use its many features we've designed a breakout/development board – by Tim Blythman

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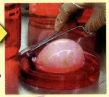

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Other DAB+ tuners include FM but not AM. Our new DAB+ tuner gives you the best of all three worlds! Build it yourself and Save – Page 28

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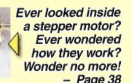

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You might expect FREE PCB software to be pretty useless . . . but you'd be wrong! CircuitMaker is great for those one-off PCB files – Page 78

PicoKit

No more "I'm bored" during the summer holidays! Get them to build this PicoKit Robot for summer holiday fun . . . and learning! – Page 86

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Editor Emeritus
Leo Simpson, B.Bus., FAICD

Publisher/Editor
Nicholas Vinen

Technical Editor
John Clarke, B.E.(Elec.)

Technical Staff
Jim Rowe, B.A., B.Sc
Bao Smith, B.Sc
Tim Blythman, B.E., B.Sc

Technical Contributor
Duraid Madina, B.Sc, M.Sc, PhD

Art Director & Production Manager
Ross Tester

Reader Services
Ann Morris

Advertising Enquiries
Glyn Smith
Phone (02) 9939 3295
Mobile 0431 792 293
glyn@siliconchip.com.au

Regular Contributors
Dave Thompson
David Maddison B.App.Sc. (Hons 1), PhD, Grad.Dip.Entr.Innov.
Geoff Graham
Associate Professor Graham Parslow
Ian Batty

Cartoonist
Brendan Akhurst

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Editorial office:
Unit 1 (up ramp), 234 Harbord Rd, Brookvale, NSW 2100.

Postal address: PO Box 139, Collaroy Beach, NSW 2097.

Phone (02) 9939 3295.

E-mail: silicon@siliconchip.com.au

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Editorial Viewpoint

It's getting hard to avoid tiny SMDs

One of the challenges of planning content for SILICON CHIP is trying to maintain a good mix of projects. We need simple ones for beginners, more complex projects for advanced constructors, plus some designs of intermediate complexity. And then we need to publish some with micros and some with analog circuitry only, as some people love micros and others hate them.

Then we have to consider the construction techniques used in each case. Do we stick with all through-hole components, use all SMDs instead, or some combination of the two?

Where possible, we prefer to use commonly available through-hole parts, because that's what the majority of readers are used to. But in some cases, we need to use surface-mounting devices (SMDs) instead. Their compactness allows us to design smaller, more feature-packed boards.

But probably the most crucial advantage of designing with SMDs is the much broader range of parts to choose from. No doubt some through-hole parts will be available for decades to come, but many newer parts (especially ICs) are not being released in through-hole packages at all. So if we want to use modern parts, we have to include at least some SMDs in our designs.

Take the world-leading DAB+/FM/AM Radio project in this issue. It is based around an Si4689 digital radio IC which is only available in a tiny 48-pin QFN SMD package. It doesn't even have *any* leads – just pads under the chip. That's ideal for commercially assembled boards using infrared solder reflow, as the result is exceptionally compact. But it makes the chip difficult to solder by hand.

But to build a radio which can tune into DAB+, FM and AM broadcasts, we had no other realistic choices.

While soldering this chip can be a challenge, you don't need expensive tools to do so. A low-cost hot-air reflow rig (available for less than $50) plus a syringe of solder paste and a steady hand is enough to do the job. That's how we built our first prototype, and it worked fine.

It isn't just the main chip, either. To get good performance out of a radio chip like this, you must keep the critical components very close to the main IC. The only realistic way to do this is to use small SMD components, including tiny passives.

The good news is we are planning to offer a limited run of PCBs with the QFN chip already soldered, for those who want to build the radio but don't think they can solder the QFN chip. We are also thinking about offering boards with both the QFN chip and the surrounding small passive components already in place.

There are numerous other SMDs on the board, but most of them are much easier to solder than the main chip and the parts immediately surrounding it. So building the radio will still be much easier.

Maintaining a good mix of projects

As I noted above, I realise that we need to publish a range of different electronic projects to keep all of our readers happy. But lately, we have published quite a few microcontroller-based projects and not so many analog or discrete designs.

I love analog designs, especially audio circuits and power supplies. I think that some of my best design work has been in the analog realm. So we will be addressing that imbalance over the next few issues. You can expect to see more analog and discrete designs in the magazine in coming months.

Nicholas Vinen

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Request for features for new DAB+/FM/AM radio project

I read with interest your upcoming project of a DAB+/FM/AM radio. I will certainly be building it.

I hope it's not too late to request that it be made as an alarm clock radio. Perhaps this could be an optional program.

I'm sure this form would increase its appeal. It should show the time in a large font normally with provision via a touch button to branch to the radio functions.

Thanks for a great magazine.

Jack Holliday,
Nathan, Qld.

Response: the radio has been in development for close to a year now and you will see the first article on the design in this issue.

It should be possible to add a clock/alarm feature with a future software update (and the addition of a real-time clock module).

Once we have finished publishing this project, which is now essentially complete, we will consider adding the clock/alarm feature.

As you will see when you read the article, we were already planning to provide future upgrades.

More doubts over eHealth Records

Your November 2018 editorial highlighted many good points in favour of the Government's "My Health Record", which in theory can be beneficial. However, in practice, there are some opt-out considerations.

A doctor will not necessarily make faster or cheaper diagnoses using My Health information. As a professional with legal responsibility, they cannot simply rely on My Health. They have no way of knowing how reliable past information is, and there could be subsequent issues that are not in the record. It is professionally and legally prudent to do more investigations.

Every doctor has to consider what they might have to say in front of a coroner.

The My Health record would, at best, be a rough guide, and at worst, misleading. Would a serviceman rush to fix an electronic device based on what the last serviceman found? It might save a bit of time, but most often, it would waste a lot of time.

There are two related security considerations. The first is debatable, but the government says we can trust them to keep our records secure. Our governments, and governments everywhere, have abysmal IT histories. Think of the online census.

Second, online criminal groups go to a lot of effort to get credit card details, even though they are not very profitable. They can only use card details briefly before unusual transactions are noticed, or the breach is exposed, and everyone cancels their cards and gets new ones.

However, criminals pay really big money for health records yielding personal information that can be harvested for years' worth of identity theft. Things like full name, date of birth, next of kin, Medicare numbers etc are all there. You cannot rush out, cancel your name and date of birth, and get new ones.

My Health is a gold mine for criminals, and they will go to extraordinary lengths to get into it. Remember, a cybercriminal only needs to get lucky once, but the government has to stay lucky all the time.

Neal Krautz,
Kedron, QLD.

Nicholas responds: no doubt you are right that eHealth records cannot be 100% reliable. But nor are the oral histories which are given each time you see a doctor (which gets old fast). How can you remember your whole medical history each time, and that of your family members? I know I can't.

And many of the questions they ask are almost impossible to answer reasonably. They often ask: "Do you have any allergies?"

Well, I probably do, but how would I know? I have never been tested for any allergies but I sometimes have what I think is probably a mild allergic reaction. I can't always pin down the cause. It has never been bad enough for me to worry about. But to answer "no" would not be wholly accurate, would it? I could spend half an hour attempting to answer that question accurately.

It would be easier to document it once and not have to be asked each time.

No doubt, those of us who are old enough to remember all sorts of government stuff-ups will agree with you that they cannot be trusted to secure our records. But pretty much all of our health system is government-run or regulated. If you can't trust them with your health records then how can you trust them with your health?

Comments on Useless Box and Fan Controller

I have to comment on the Useless Box project that was published in the December 2018 issue (**siliconchip.com.au/Article/11340**). What a gem! I think that the name is inappropriate otherwise almost every toy in the world would be condemned as useless. Surely, this must bring some joy to kids.

The same sort of thing could have been made as a program on a computer but I doubt if it would have had the same appeal and impact as a physical device. The real thing cannot be simulated. It is not useless.

With respect to the Four-channel High-current DC Fan and Pump Motor Controller, is it wise to locate it under the bonnet of the car? From the picture in the magazine, it is shown as just behind the radiator fan and therefore will

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receive airflow. However, that is after the air has been heated by the radiator and the other cars while waiting for the traffic to move.

During last summer, my automotive technician neighbour gave me a lot of dead car parts and many appeared to have died from heat stress. Just yesterday, he gave me another one and summer has hardly started. There were none during autumn, winter and spring.

George Ramsay,
Holland Park, Qld.

Response: we're glad you liked the Useless Box. You are right that it's better to keep electronics out of the engine bay of any vehicle; however, our Fan/Pump Controller has been designed with high ambient temperatures in mind. The electronics in it are not particularly stressed, even at the full rated current, so are unlikely to fail from heat stress.

*Its predecessor (January 2018; **siliconchip.com.au/Article/10938**) has been installed in the same position in the vehicle for nearly a year and does not appear to have suffered from it. That's despite the very high under-bonnet temperatures that particular engine generates when sitting in traffic.*

If you can easily install it inside the vehicle, so much the better, but that will generally mean longer wiring runs and extra cables going through the firewall, which we prefer to avoid.

Small hifi amplifier wanted

With many more people living in apartments, people are looking for hifi gear that isn't too loud, which might otherwise upset their neighbours. They also want more flexibility, eg, Bluetooth support, WiFi and digital connectivity so users can stream their latest favourites on Spotify etc.

While your recent SC200 amplifier design (January-March 2017; **siliconchip.com.au/Series/308**) was excellent, it is overkill for many. Would you ever consider a more modest output amplifier in a smaller form factor with similar high-end specs which also had Bluetooth, WiFi and digital facilities?

Commercial offerings are pretty ordinary with very high distortion specs and I am sure a lot of readers would be interested in such an offering.

Nick Allan
Canberra, ACT.

*Response: we already published a smaller high-quality amplifier in the October & December 2013 and January 2014 issues, called the Tiny Tim (**siliconchip.com.au/Series/131**). It was a higher-power version of the High-Performance Stereo Headphone Amplifier from the September and October 2011 issues (**siliconchip.com.au/Series/32**).*

We can tell you from experience that this works very well in an apartment context, generating more than enough volume (with reasonably efficient speakers) for the average room while consuming little power and taking up little space.

It doesn't have Bluetooth or WiFi but there isn't much point adding such functions to an amplifier these days since dongles to do those jobs cost just a few dollars. Search eBay or AliExpress for "Bluetooth audio receiver" and you will find many decent options. They usually run off a 5V USB power supply and have a 3.5mm stereo jack socket that can be connected directly to the amplifier inputs.

*If you need a specific recommendation, this one is very cheap and works reasonably well: **www.aliexpress.com/item//32614607189.html***

We've also had some pretty good results purchasing low-cost pre-built amplifiers with built-in Bluetooth. Sure, they don't have the low-distortion specifications of our Tiny Tim or SC200 but Bluetooth sound quality isn't really hifi anyway so it hardly matters.

*We can recommend this one; it's compact, the Bluetooth works extremely well and the sound quality is at least decent: **www.aliexpress.com/item//32805899758.html***

It only cost us around $25 including postage, although the price has gone up a little since then. It's still excellent value, though.

Pump problem blamed on dodgy installation

Concerning M. B.'s pump problem described in the Ask SILICON CHIP section on page 100 of the August 2018 issue, your answer provides an electronic solution to what should be a non-problem!

M. B. does not have a fault with his water-pump set-up, as distinct from having the pumping plant incorrectly installed in the first place. The bone-head that did the job should

have installed a one-way, non-return valve (ie, a check valve) on the pump outlet. It would prevent the pressure vessel from discharging through the pump. This is an inexcusable error of omission.

Moreover, the pump controller should incorporate a "run-dry" protection feature. In the event of the foot valve failing, M. B.'s first warning should be that no water is coming out of his taps since his pump will have lost its prime. That should be a pretty obvious indicator that something is wrong!

Andre Rousseau,
Auckland, New Zealand.

Minor error in USB Digital/SPI Interface board

Thanks for the USB Digital and SPI Interface Board project that you published in the November 2018 issue (siliconchip.com.au/Article/11299). It fulfilled a need I had – to be able to test SPI devices from a keyboard, to understand their operation before committing to a circuit and code.

I found a minor error in the PCB design. The circuit diagram (Fig.1) shows CON4 has SPI data out (DO/MISO) on pin 4. Table 1 also has CON4 listed as MISO/DO on pin 4. But in fact, pin 4 is not connected on the PCB. I just needed to add a short link to pin 10 on IC1, easily accomplished on the underside of the board. Connector CON3 has DO on pin 3 as expected.

I tried an SPI loopback test initially, using CON4, and naturally, this was the one with the error. If I had tried CON3 first, it would have worked straight away. Thanks, it is a very useful little circuit and system.

John Leis,
Toowoomba, Qld.

Response: you are correct, that track is missing from the design. We will fix it in the next batch of PCBs that we order.

GPS Frequency Reference parts list is incomplete

Now that I have received the set of SMD parts for the GPS-Synched Frequency Reference that I ordered from your Online Shop, I noticed that there are a couple of items missing from the Parts list on page 33 of the October 2018 issue. The header socket for CON1 is not in the list, nor are the Dupont connectors for the GPS wiring.

David Williams,
Hornsby, NSW.

Response: you are correct on both counts. We forgot to include those in the Parts list. We will publish an erratum explaining that.

Guitar Jammer gain questioned

I built your Guitar Jammer project from the October 2000 issue (siliconchip.com.au/Article/4285) some time ago from an Altronics kit. I've made a few modifications to it but I found the basic design to work exceptionally well.

But I can't figure out how you calculated the gain of the LM386 IC (IC1) as 33 times, as stated on page 23 of that issue. I've calculated the gain with a 220Ω resistor and 10µF electrolytic capacitor between pins 1 and 8 as giving a gain of approximately 90. Surely the extra 12µF of capacitance won't have such a dramatic effect on the gain.

Please keep up with the good work.

John Rigon,
Werribee, Vic.

Response: we think you are right, that the gain is around 88.5 times. This is quite easily calculated, as the gain is $30k\Omega \div R$ where R is the value of the internal 1.35kΩ resistor in parallel with the external resistor. As you say, the change in capacitance will not affect the DC gain, just the frequency response.

Even if you take account of the fact that the resistive mixer feeding pin 3 of IC1 will reduce the signal level from a single input by half, that still gives an overall gain of around 44 times, not 33 times as stated in the article. That was published quite a long time ago and so we don't know where the original figure came from.

HMV 904 restoration and the 405-line TV standard

I read with admiration Dr Hugo Holden's painstaking and thorough restoration of a 1939 HMV 904 television/radio in the November 2018 issue (siliconchip.com.au/Article/11314).

These are rare sets, and Dr Holden's work in preserving this outstanding piece of late 1930s electronics reminds me of a saying: "if it was handmade, it's probably hand-repairable." The article contained useful (and inspirational) details on pretty well every aspect of restoration, and should be in every restorer's reference library.

I noted that the 405-line standard was described correctly as using positive modulation for the vision signal:

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the brightest parts of the scene produce the greatest transmitter output.

That makes intuitive sense, but follow-on NTSC and CCIR/SECAM/PAL systems (including our now-defunct black-and-white and colour analog systems in Australia) used negative modulation, where it's the darkest parts of the scene that produce maximum transmitter output.

Firstly, synchronising pulses take the video signal below picture black level, they are "blacker than black" For a baseband 1V peak-to-peak video signal, black is around 300mV, sync tips are 0V.

With positive modulation, sync tips equate to near-zero transmitter power, making reliable separation on weak signals difficult, so that weak signals commonly lose sync and the picture becomes unusable.

Negatively-modulated systems put peak power at the sync tips – the strongest part of the transmitted signal. Thus virtually any signal (no matter how weak) will produce a useful image. I recall, one summer back in the 1960s, turning on our family TV set in Adelaide to discover that our local ABC2 was off the air. All was not lost. There, faint but just stable and legible, was the test pattern from ABQ2 in Brisbane.

Second, noise peaks add to the strength of the received signal. With positive modulation, these are visible as bight flashes. Negative modulation renders these as dark flashes, which are less distracting.

Finally, the Average Picture Level (APL) for well-lit scenes (whether studio or outdoors) is around 50%, more if you're outside at a ski resort. With positive modulation, the transmitter's average power output is correspondingly high on very bright scenes, placing extreme demands on the transmitter output stages, cooling and power supplies.

Negative modulation lowers the average transmitter output overall, relaxing demands on the equipment.

Again, let me offer my congratulations to Dr Holden for his excellent article, and to SILICON CHIP for publishing this testament to the restorer's art.

Ian Batty,
Harcourt, Vic.

Super-7 100mm speaker part number has changed

I am building the Super-7 AM Radio from the November and December 2017 issues (**siliconchip.com.au/Series/321**). I am having trouble finding the right loudspeaker, so I read with interest your answer in the Ask SILICON CHIP section of the August 2018 issue, on page 97 ("Source of Super-7 AM Radio parts").

The parts list for this project called for a 100mm (4-inch) 4Ω or 8Ω speaker. The reply to this question was: "The speaker John used was a Jaycar part, catalog code AS3008."

A quick check of Jaycar's website shows that the AS3008 has a square surround and does not resemble the speaker shown in your AM Radio.

Jaycar's AS3007, which is listed as a 125mm (5-inch) speaker has a circular surround, fits perfectly on the PCB and looks identical to the one shows in the photos of the prototype.

Presumably, when you referred to AS3008, you meant to refer to AS3007 instead.

Bill Walters,
Kareela, NSW.

John responds: the speaker initially purchased for the prototype was sold as AS3008 but it appears that its catalog code was changed to AS3007 around the time the Super-7 articles were published, to make room for a slightly different speaker which is now sold as AS3008.

While the current AS3007 is described as a 5-inch speaker (125mm), the cone including surround is actually about four inches in diameter (100mm). Both the AS3007 and AS3008 are suitable for the Super-7 AM Radio; they both fit the cut-out and holes provided on the PCB.

High voltage linear power supply wanted

I read with interest the letter from J. R. in the Ask SILICON CHIP pages of the September 2018 issue, regarding sourcing parts for an old *EA* lab power supply design. I've been searching for a new linear lab power supply to replace my old 30V/1A *EA* design (January 1985). Although this has performed well for many years, I find the output voltage and current are both insufficient at times.

An output of 0-50V and current in the 5-10A range with an LCD screen and current limiting would make for a genuinely universal bench supply, suitable for a large number of uses. It seems neither Jaycar or Altronics have such a unit. Most are around 0-30V, or lower, with higher current outputs.

Would SILICON CHIP consider producing a new, updated design as there seems to be a void in the market for higher voltage power supplies?

Cameron Wedding,
Coorparoo, Qld.

Response: that is a good idea. We haven't published a power supply design in a while. While a 50V, 5A+ linear supply would have to be quite large, with a big transformer (probably 300-500VA), a large heatsink, a fan and multiple transistors, it's certainly possible. We will add it to our list of future projects.

While Jaycar and Altronics sell many good entry-level power supplies, you will find a broader range of equipment available from specialist test equipment vendors like Emona or Trio Test & Measurement. However, while these have many great options, most of them are not linear and the higher-voltage, higher-current models can be quite expensive. So a DIY linear supply makes sense.

One thing to keep in mind when looking at commercial bench supplies is that often they have multiple outputs

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that can be combined in series or parallel. So a 2 x 30V 5A supply could be used as a 60V 5A supply, a 30V 10A supply or a ±30V 5A supply.

Why is fluorescent lamp driver so complicated?

Recently, I had a small fluorescent lamp of Chinese manufacture fall into a washbasin full of water while it was switched on. Not surprisingly, it stopped functioning. As it was just a 5W lamp, I figured there was nothing much inside to go wrong, perhaps only a starter or such, so I decided to try to repair it.

Opening it resulted in complete destruction of the plastic housing, as it was so thoroughly glued together that there was absolutely no other way to get in.

Well, I was really surprised when I finally got a view of its insides. I can't imagine how you could make such a lamp more complicated. Interestingly enough, it included a fuse that is only accessible if you destroy the lamp.

Not very environmentally appropriate. How the Chinese can put in so much complicated and in my opinion unnecessary electronics and still sell these things for almost nothing is a riddle to me.

I really enjoy the magazine. Congrats on producing such interesting articles.

Christopher Ross,
from Germany via email.

Response: That design is not necessarily over the top.

I count 12 resistors, 10 diodes, nine non-polarised (plastic) capacitors, three electrolytic capacitors, three transistors plus a fuse, inductor, choke and transformer. That's a total of 43 components. It may seem like a lot, but if you try to design a fluorescent driver circuit without any ICs (and I can't see any in yours), then the component count adds up quickly.

They would not add components without a good reason as they all cost money. Several components would be for EMI suppression, with others to improve the power factor and more for increased efficiency.

Of course, old-fashioned fluorescents only used a couple of components: an iron-core choke and a starter. But the chokes were big and heavy, and not that efficient, and they often took a while to start up. Both tended to fail over time and needed periodic replacement, so it was far from a perfect scheme.

Manufacturers are trying to make products these days which are more user-friendly and that requires more complex designs.

Most of the components in your lamp would cost the manufacturer cents (if that). So they have probably optimised this design to keep costs down while complying with EMI, power factor and efficiency requirements.

It's true that having more components means more to go wrong but a good design with quality components should still last. For all you know, if it had not had a bath, it may have lasted for many years.

*By the way, if you have a copy of our September 2002 issue, have a look at the Fluorescent Tube Inverter project (**siliconchip.com.au/Article/4027**). That may give you an idea of why there are so many components. That design used ICs (three, in fact) and still had a total of around 65 components!*

And being an older, non-commercial design, it would not have to meet the EMI and other requirements that your lamp would.

We also hate designs where you have to destroy the case to get them open, making them effectively unrepairable. That's the real problem with your lamp. The fuse is just there to prevent a fire; they don't expect you to replace it if it blows, which would typically result from the failure of another component.

NBN equipment design risks accidental damage

There are many design features of the NBN which beggar belief. We have Fibre to the Curb (FTTC) (shouldn't it be spelled Kerb in Australia?). It is connected from the street into the house via a standard RJ11 plug and socket, as normally used for analog telephones.

In my installation, the NBN's FTTC Network Connection Device (NCD) delivers 53V to the street to power the fibre to copper interface equipment.

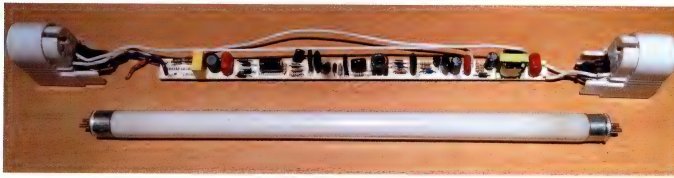
Note that while the old telephone system also supplied around 50V to power the phone ringer, this would drop to 6-12V @ 50mA under load (eg, with the phone off the hook), whereas the NCD's voltage source is low impedance and so would deliver a much higher voltage to similar loads.

It would be very easy to connect a cord from the NCD (with the RJ11 plug) to any number of other devices by mistake, such as analog telephones or an RJ45 LAN connection to a computer or router (an RJ45 socket will accept an RJ11 plug). That could do all manner of damage to those devices and they are commonly located close to the NCD plug.

There are warnings on stickers which are attached during the installation, warning the user not to connect the NCD to the wrong equipment. But why on earth didn't the designers of the NBN select a plug and socket that was unique to the FTTC installation, to make it impossible to connect the wrong equipment? It seems like a bizarre engineering decision.

Ken Moxham,
Urrbrae, SA.

Response: we agree that manufacturers should not make



equipment with standard types of plugs/sockets unless that equipment is compatible with other equipment already using those kinds of plugs and sockets.

We know of at least one instance where (pre-NBN) a consumer purchased equipment that was powered from a plugpack terminated in an RJ11 plug. And, you guessed it, after moving, they plugged that into the RJ45 LAN socket on a computer, destroying its motherboard.

The manufacturer could have used a DIN plug/socket (as is typical for non-standard power supplies) or some other type of connector to avoid that situation. It's just common sense – something that design engineers should have in abundance.

Back-to-base security systems and the NBN

Many of your readers will have home security systems linked to monitoring services which can alert a list of prearranged people via telephone when the alarm goes off. Alerting these people can prevent claims for loss or damage, so some insurers offer premium reductions when such systems are installed.

With the NBN and many of us dropping the landline service, the security system is no longer connected. The only solution offered by insurers is to move backwards and install a 3G/4G phone link which of course is not compatible with many older security systems, so they end up selling a whole load of new stuff and increased service charges.

Could Silicon Chip review this situation and devise a solution? For example, a security system autodialler replacement could be linked directly to the NBN or via WiFi, emulating the old dialer function.

David Kitson,
Claremont, WA.

Response: at least for those with FTTN/FTTC/HFC services, moving to the NBN should not present a problem for this type of alarm system. After all, these versions of the NBN provide an analog telephone port (the FTTN service at our office provides two by default).

Of course, it is translated to VOIP and sent over the NBN connection but the alarm system doesn't know that – as far as it is concerned, it is connected to a "plain old telephone system" (POTS) and it can make alarm calls in the usual manner.

We can think of only two reasons why this should present a problem: one, if power to the premises is cut, you need the NBN telephone port to remain active so that the alarm can dial out and two, your alarm system may not be anywhere near the NBN modem. But there are simple solutions to both of these problems.

To solve the power problem, you need to run the NBN modem and any other related devices from a UPS.

If you're using FTTP there is a specialised battery backup that is optionally installed. It uses a 12V 7Ah SLA battery that you have to purchase yourself (about $35). FTTC should work on a similar principle that everything will run if you have a UPS acting as a backup power source.

If you're on FTTN then the node will have an internal battery backup in the case of a power outage, so all you need is a UPS for your own devices, assuming the node itself is still being powered.

For HFC, there's unlikely to be a backup power source for your connection, meaning that a UPS will likely not help in the case of a blackout.

Of course, if the exchange itself loses power you're out of luck no matter what NBN distribution method you have, but that's unlikely to occur.

If a bog standard UPS doesn't work, you may need one with a pure sinewave output. They are not that expensive (around $200). Maybe a reader who installed a UPS for use with their NBN connection can tell us what works best.

As for the inconvenience of running a telephone cable from the alarm controller back to the NBN modem, you also have the option of using a low-cost VOIP Telephone Adaptor (eg, the Cisco SPA112). It needs a network link back to your modem but that could be via WiFi if necessary, using a second wireless access point (which would also need to be on a UPS).

When our office was switched to the NBN, Telstra supplied a two-port telephone adaptor along with a modem with two built-in analog telephone ports. We connected these to our three-port PABX (Private Automatic Branch Exchange) and it worked straight away, as if it was still connected to the analog telephone lines.

The 3G/4G option you've mentioned is the best option in our opinion. You can get 3G/4G to POTS "diallers" quite cheaply. Here is one we found for less than $100, which claims to support 3G (note that the 3G network may shutdown as early as 2020), although we haven't tried it: ***siliconchip.com.au/link/aame***

We have family members with back-to-base alarms using that sort of dialler and it appears to work very well. And since the unit can be powered from 5-12V DC, it can run off the alarm battery (perhaps with a linear regulator to drop the voltage for it). **SC**

It's come a long way in a short time . . .

by Dr David Maddison

The latest in 3D Printing

Three dimensional (3D) printing has been around since the 1980s but there have been many improvements to the technology since then, especially of late. This includes much lower printing costs, higher printing resolution, faster printing, improved materials and more material variety, the ability to print much larger parts and more user-friendly printers.

Design. Print. Assemble. Drive. That's the slogan of Divergent 3D Blade, who created the 2015 concept car shown above. The driver sits in a 3D "painted" aluminium and titanium chassis – an example of what modern technology can achieve.

3D printing is also known as additive manufacturing, to indicate that parts are built up by adding more material onto them, distinguishing it from traditional machining processes used in manufacturing such as milling and turning, which start with a larger piece and then removes surplus material to arrive at a final object.

Initially, the primary use for 3D printing was to quickly make prototypes of components to evaluate and test them before committing to a full manufacturing process. For example, a part could be made in plastic to test it for fit, functionality and appearance and then later manufactured in metal.

While still used for this purpose, due to improved strength of materials and processes it is now possible to create objects directly that are structurally sound and suited for an end-use application such as aircraft, automobile or satellite parts. Processes have also been developed that make it possible to rapidly produce a large number of parts for a mass-production environment.

While the terms 3D printing and additive manufacturing are loosely interchangeable, they have come to have somewhat separate meanings in the industry. 3D printing is commonly understood to refer to the lower end of the market, including domestic printers; additive manufacturing has come to refer to industrial-scale equipment and processes suitable for commercial design and production processes.

However, there is some overlap and even disagreement with the terminology. For simplicity, we will refer to all these technologies as 3D printing in this article.

Main types of 3D printing

There are seven main types of 3D printing processes, as defined by the ISO/ASTM 52900:2015(en) standard and they are as follows:

1) Binder Jetting, an "additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials" (see Fig.1).

In this process, a binding agent is deposited onto a powder bed to bind particles together, which will form the desired part. Once one layer has been finished, the powder bed is lowered and a new layer of powder is spread over the build area. The process then repeats until the object is finished.

One variation of this process uses sand or similar

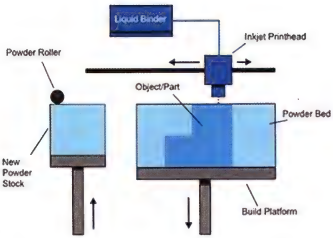


Fig.1: the Binder Jetting process.

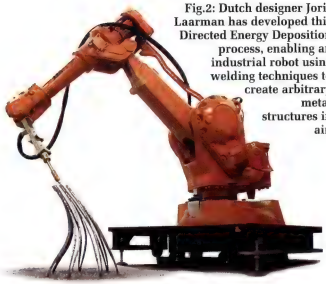


Fig.2: Dutch designer Joris Laarman has developed this Directed Energy Deposition process, enabling an industrial robot using welding techniques to create arbitrary metal structures in air.

powder materials; another uses metal powder. Dimensional accuracy is typically around 0.2mm with metal or 0.3mm with sand.

It is a low-cost process with applications including making sand casting moulds and cores for metal casting (Sand Binder Jetting). Large objects can be produced. When metal is used (Metal Binder Jetting), the part can be finished off by heating in a kiln to sinter the component. Voids in the metal can then be filled with another metal that has a lower melting point.

2) Directed Energy Deposition, an "additive manufacturing process in which focused thermal energy is used to fuse materials by melting them as they are being deposited… Focused thermal energy means that an energy source (eg, laser, electron beam or plasma arc) is focused to melt the materials being deposited".

This process is similar to welding; in one example, a wire spool is fed to an electric arc which melts the wire and deposits metal onto the piece being worked on, typically under the control of a robotic arm with five- or six-axis control (see Fig.2). Very large objects can be made with relatively coarse accuracy.

3) Material Extrusion, an "additive manufacturing process in which material is selectively dispensed through a nozzle or orifice".

In Material Extrusion, a filament of plastic is pushed through a heated nozzle which is moved in a predefined pattern onto a workpiece on a build platform. After one layer of plastic has been deposited, either the nozzle is moved away from the workpiece, or the workpiece is moved away from the nozzle, allowing further layers to be built up (see Fig.3).

The technology used is called Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF). Dimensional accuracy is typically around 0.5mm. Parts can be brittle, depending on the material used, and not always suitable to withstand mechanical loads.

A variety of plastic types and colours can be used. This is the most common and cheapest form of 3D printing and

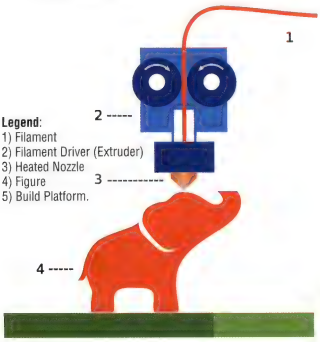


Fig.3: 3D printing a figure using Material Extrusion. Author: Wikimedia user Kholoudabdolqader.

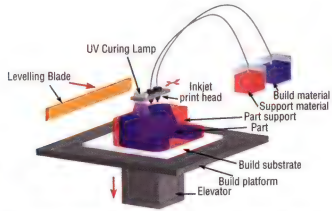


Fig.4: the Material Jetting process. Build material and support material is ejected from print heads and cured by UV light after it has been deposited. The build platform is then lowered and the process repeated.

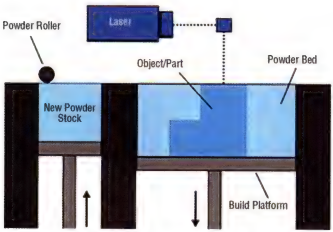


Fig.5: the Powder Bed Fusion process, in which a laser fuses a powder layer in the shape of a slice of the desired object. The build platform is then lowered, covered with a fresh layer of powder and the process repeats.

is typically used by the hobbyist. Additional structures often need to be printed to support overhanging areas during printing, then removed when printing is complete.

4) Material Jetting, an "additive manufacturing process in which droplets of build material are selectively deposited ... Example materials include photopolymer and wax."

Material Jetting is a process in which a photosensitive build material and a dissolvable support material is deposited on a build platform and then the build material is cured with UV light.

Layers are built up one at a time, as with other 3D printing processes (see Fig.4).

Deposition is similar to the process of an inkjet printer and is done line-by-line. A combination of both build material and support material can be used. The support material is designed to be washed away or otherwise removed at the end of the process. Typical uses for this technique are multicolour prototype production and creating medical models. An accuracy of 0.1mm can be achieved.

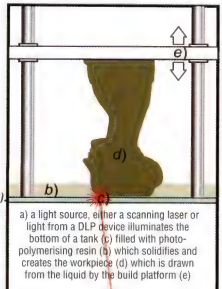
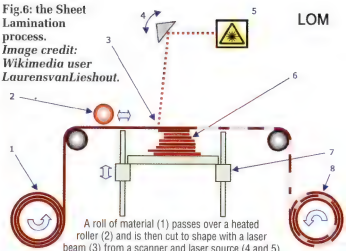


Fig.7: the Vat Photo-polymerisation process. ***Image credit: Scopigno R., Cignoni P., Pietroni N., Callieri M., Dellepiane M. (2017) "Digital Fabrication Techniques for Cultural Heritage: A Survey". Computer Graphics Forum 36 (1): 6–21. DOI:10.1111/cgf.12781.***

Fig.6: the Sheet Lamination process. ***Image credit: Wikimedia user LaurensvanLieshout.***



The resulting parts are brittle. Drop on Demand or DOD is a variation of this process.

5) Powder Bed Fusion, an "additive manufacturing process in which thermal energy selectively fuses regions of a powder bed".

In this process, a metal or polymer powder layer is fused by a thermal energy source and as each layer is completed, the work platform is lowered and a new layer of powder is deposited and the process is repeated until the workpiece is finished (see Fig.5).

When creating metal objects, a laser is typically used for Direct Metal Laser Sintering (DMLS) or Selective Laser Melting (SLM), or an electron beam for Electron Beam Melting (EBM). Dimensional accuracy of 0.1mm can be achieved with metals such as aluminium, stainless steel or titanium.

Fully functional metal parts can be directly produced for aerospace, medical or dental applications.

With polymers, the process is called Selective Laser Sintering (SLS). Nylon is typically used and the dimensional tolerance is 0.3mm. Functional parts can be produced.

Powder bed fusion has the advantage that no support structures need to be printed as the powder supports any overhanging structures above it.

6) Sheet Lamination, an "additive manufacturing process in which sheets of material are bonded to form a part".

Sheet Lamination, also known as Laminated Object Manufacturing, is a process in which sheets of materials such as paper or foil are cut with a knife or laser and

Fig.8: the 3D-printer optimised antenna bracket for the Sentinal satellite, made from aluminium alloy. ***Image source EOS GmbH.***

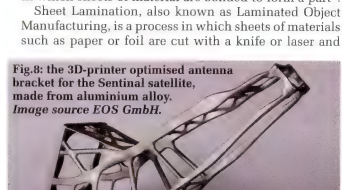


Fig.9: this shows how the design intended for traditional manufacturing was converted to a version optimised for 3D printing. *Image source EOS GmbH*

adhered together, building up one sheet at a time as the build platform is lowered with each layer deposited (see Fig.6).

7) Vat Photopolymerisation, an "additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerisation".

In Vat Polymerisation, a photosensitive liquid prepolymer resin is polymerised or cured by the application of a light beam. As each layer is polymerised, the object being printed is lifted from the liquid. Dimensional accuracy of up to 0.15mm can be achieved (see Fig.7).

The two main technologies are Stereolithography (SLA) and Direct Light Processing (DLP). In SLA, a laser is used to draw the desired pattern of a given layer by driving it across the workpiece in the X an Y directions.

In DLP, the pattern for each layer is drawn all at once with a digital light projector. Good surface finishes are possible.

Recent advances in the technology

We will now take a look at some recent advances in 3D printing technology. Due to the vast number of 3D printed products being produced, it is impossible to cover all of them, so in some cases, only representative examples of each will be presented.

Aerospace components

Many Aerospace components can now be produced directly in their final form using 3D printing. Moreover, the component design can be optimised for strength and lightness by taking advantage of the unique capabilities of 3D printing.

Computer software often decides the final shape of the piece, working to specific constraints such as dimensions that are imposed by the designer. As no person decides the final shape, the design can appear somewhat "organic", like shapes produced in nature.

In one example, a bracket for a space satellite antenna was transformed from its original design, intended for production by traditional manufacturing techniques, to a design which takes advantage of 3D metal printing techniques.

The 3D printed component weighs 940g compared with the traditional component which weighs 1600g. See Figs.8 & 9.

Fig.11: this bicycle has a 3D printed stainless steel frame. It was made by students at TU Delft in the Netherlands, by welding of beads of material using a robotic arm and Directed Energy Deposition.

Fig.10: this bicycle from Arevo has a 3D printed plastic frame.

Bicycles and bike tyres

There are two claimants for the world's first 3D printed bicycle frame. One is San Francisco-based Arevo (**https://arevo.com/**) who made a plastic framed bicycle with a polymer called PEEK (polyether ether ketone) – see Fig.10. The frame is said to be stronger than titanium.

The other contender is UK-based company Renishaw (**www.renishaw.com/en/**) who worked in conjunction with Empire Cycles to make the first metal 3D printed bicycle frame. The frame was made in sections in titanium and then the sections were bonded together (see Figs.12 & 13).

An Australian company, Bastion Cycles (**http://bastion-cycles.com/**) is making custom bicycles with 3D printed frame lugs (Fig.14). Another company, BigRep (**https://bigrep.com/**), based in Berlin, has produced an airless 3D printed bicycle tyre (Fig.16). BigRep also makes very large 3D printers, with a build volume of up to one cubic metre.

Clothing

Clothing is now being produced with 3D printing, many items with bizarre designs. Unfortunately, copyright restrictions by the designers prevent any images being shown here.

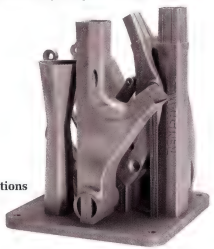


Fig.12: the titanium sections of the Renishaw bike, in the form that they came out of the 3D printer.

Fig.13: the assembled Renishaw titanium bike.-

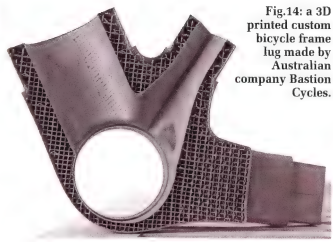


Fig.14: a 3D printed custom bicycle frame lug made by Australian company Bastion Cycles.

Custom 3D printed shoes

A company called Feetz (https://feetz.com/, *"The Digital Cobbler"*) is, or soon will be, making 3D printed shoes to order (see Figs.15 & 17). Their FAQ page is at: https://feetz.com/faq

To order shoes, the customer downloads an App to their smartphone and uses it to take three pictures of each foot. This provides enough information to generate a 3D model of each foot, which is used by a 3D printer to make the custom shoes.

The shoes are designed to last the industry standard of 800km of walking or six months of wear.

The Feetz YouTube channel can be seen at: siliconchip.com.au/link/aam3 Also see the independent early product review from May 2017 in the video titled *"Feetz Shoes Review – 3D Printing Shoes"*, viewable at: https://youtu.be/Ta_1lTa55zo

Digital Light Synthesis by Carbon

Digital Light Synthesis is a vat synthesis 3D printing technique by a company called Carbon (www.carbon3d.com/). They make 3D vat polymerisation equipment with production rates suitable for mass production.

Their 3D printing technology has enabled Adidas to make a shoe with a unique midsole which would be impossible to make by any method other than 3D printing. The midsole is printed with a high-performance elastomeric polyurethane material (Fig.18). See the video titled *"Carbon M1 Super Fast 3D Printer Demo"* at https://youtu.be/O2thSsQrZUM

3D printing food

Fused Deposition Modelling isn't just used with plastics. It is also possible to use the same technique with edible substances. As a result, it's possible to 3D print food so long as the ingredients can be pureed so that they can be squeezed through the extrusion nozzle.

3D printing of food allows great flexibility in the artistic presentation of food, as well as creating designs that would be difficult or impossible to do by conventional techniques. Unfortunately, the texture of the resulting food reflects its pureed origins, so there can be no chunky or chewy aspects to the creations as in regularly prepared food.

Some examples of commercially available 3D food printers are:

- the byFlow Focus (www.3dbyflow.com/home-en)
- Choc Creator (http://chocedge.com/)
- CheFJet – see Fig.20 (https://au.3dsystems.com/culinary/collaborations)
- DISCOV3RY COMPLETE (www.structur3d.io/)
- Foodini (www.naturalmachines.com/) – see Fig.19

Fig.15: Feetz brand 3D printed custom footwear.

Fig.16: the 3D printed airless bicycle tyre from BigRep.

- MMuse Touchscreen
- several different machines by Procusini (www.procusini.com/)
- Wiiboox Sweetin (www.wiiboox.com/3d-printer-wiiboox-sweetin.php)
- ZMorp Thick Paste Extruder (https://zmorph3d.com/products/toolheads/thick-paste-extruder)

NASA has been researching food for astronauts made with 3D printers to help provide variety for long-duration missions such as trips to Mars or stays on the International Space Station.

A number of restaurants offer 3D printed food on the menus such as Food Ink (http://foodink.io/) in London, where all food, utensils and furniture are 3D printed; the Mélisse Restaurant (https://www.melisse.com/) in Santa Monica, California; La Enoteca at Hotel Arts in Barcelona; and La Boscana (http://www.laboscana.net/) in Bellvís, Spain.

3D printing houses

It's not only small items that can be 3D printed, but large items such as houses as well!

3D printed houses are generally built by much the same techniques as smaller objects but at a larger scale. The construction material is typically a paste-like material such as concrete (see below for an exception) that can be laid down in layers and that has enough mechanical strength to hold itself together while it sets.

Fig.17: the sole of the Feetz Axis model 3D printed sneaker.

It is important to note that the entire house is not built in one go; typically, the 3D printer forms the internal and external walls and possibly the roof. Services such as plumbing and electricity have to be installed manually as do fittings such as windows, doors, kitchen and bathroom cabinetry and so on.

3D house printers may be in the form of a super-sized desktop printer and operate in a linear XYZ coordinate system, or they may have a centrally pivoted rotating arm (see Figs.21 & 22).

Perth company Fastbrick Robotics (www.fbr.com.au/) has developed the Hadrian X, a brick laying robot which can lay the bricks for the house in a fraction of the time that a person would (see Fig.23).

While it does not work as a traditional 3D printer, in that individual pieces are laid down, it is fair to say it is a form of 3D printing.

Unlike a traditional, modern house, in the construction model used for the Hadrian X, internal walls are made of special bricks as well, which are equivalent to about 15 standard bricks in volume.

Human body parts

Human body parts can be 3D printed. This includes prosthetic devices such as stick-on artificial noses or ears (Fig.24); prosthetic limbs (Fig.25); practice parts for medical students and surgeons (Fig.26); actual working biological organs such as bladders (Fig.27); and skeletal components

Fig.18: the midsole of the Adidas FutureCraft 4D is 3D printed using Carbon's Digital Light Synthesis technology.

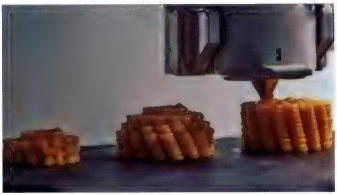


Fig.19: in this example of 3D printed food, a "corn cob" is printed by a Foodini machine. This would be extremely difficult to create by normal means but is easy with 3D food printing.

Fig.20: examples of 3D printed food novelty items made with the 3D Systems CheFJet Pro.

such as replacement hips or sections of damaged or diseased bone (Fig.28).

Other synthetic organs are under development, as well as more skeletal components.

Biological 3D printers use much the same principles as regular 3D printers but instead of printing with polymers, they print biological solutions containing living cells and matrix materials (see Figs.29 & 30). 3D printing of human body parts as replacements for damaged or diseased organs or other areas is being heavily researched right now and the replacements are already occurring.

There are different difficulty levels in printing human body parts. Flat structures such as skin are the easiest to print, followed by tubular structures like blood vessels and urethras and the next most complex are hollow organs like the bladder or stomach.

The most complicated parts to print are organs with complex "plumbing" and many different cell types such as hearts, kidneys, livers and lungs.

Human bladders produced by 3D printing are an example of an organ that is being produced and implanted in people now. This work was pioneered by Dr Anthony Atala at the Wake Forest Institute for Regenerative Medicine (WFIRM) in North Carolina, who has also engineered skin, urethras and cartilage structures in the lab.

3D printed bladders are used when a patient has a damaged, diseased or malformed organ and requires a functional replacement. A portion of good bladder tissue is taken from the patient and incubated to multiply the cells and then 3D printed to create the shape of a bladder, a process which takes two months.

There are now ten patients who have 3D printed bladders implanted, including a patient that has had an implant for 14 years. New sections of urethras have also been grown similarly and implanted in patients. The first attempts at the 3D printing of human tissues by WFIRM were made with a modified office inkjet printer, which is now in a museum.

Kidneys and livers are the organs most in demand but also the most complex to produce and work is underway to develop these for implant. See this video for more details: www.ted.com/talks/anthony_atala_printing_a_human_kidney

Fig.21: Artist's concept of the Apis Cor (http://apis-cor.com/en/) house printer. The basic structure of the house (walls etc) can be built in 24 hours. See the video titled *"Apis Cor: first residential house has been printed"* at https://youtu.be/xktwDfasPGQ

Fig.22: the world's first 3D printed house by San Francisco company Apis Cor, in conjunction with Russian developer PIK.

Lower cost metal printing

Just as the cost of plastic 3D printing has come down to make it affordable for either home users or smaller engineering establishments, so is the cost of 3D metal printing. Here are some lower cost metal printing machines.

iro3D

The iro3D (http://iro3d.com/) is a low-cost desktop metal printer costing around US$5,000 – see Fig.31. It is pos-

Fig.23: FBR Ltd's Hadrian X bricklaying robot, which can lay bricks for a house in a fraction of the time that a human would take. See the videos on their YouTube channel showing the machine at work: http://siliconchip.com.au/link/aam4

Fig.24: 3D printed prosthetic stick-on nose and ear.

sibly the lowest cost 3D metal printer on the market. It is in relatively early stages of production and was invented and produced by Sergey Singov in the USA. At that price point, it would be affordable for some home users.

The printer works by depositing in the desired form of metal powders for printing (the build material), along with sand (the support material) in the empty non-printed spaces, into a crucible in a process called Selective Powder Deposition (SPD).

Filler metal such as copper or high carbon steel is then placed on the top of the printed metal and sand workpiece, along with coke and additional sand, to prevent the workpiece metal from oxidising. The ensemble is then baked in a kiln (not supplied); the filler metal melts and "soaks" the powdered metal workpiece, binding the powder together to yield a 100% solid metal component (Fig.32).

The minimum height of a detail that can be produced is 0.3mm, the layer thickness, and the minimum width is 1mm (the pourer diameter).

Metals that have so far been tested in this printer are high-carbon steel, copper-iron and copper-nickel while mild

Fig.26: non-functional 3D printed organs for medical instruction and surgical practice that look and feel like the real thing and even "bleed". The models are produced using 3D printing to create injection moulds which are then filled with hydrogel, a polymer substance which feels like human tissue. Bleeding is simulated with bags of a blood simulant. See the video titled *"Simulated Surgery at URMC"* at https://youtu.be/Ah7gJ4Vgr-w

Fig.25: the EXO Prosthetic designed leg by William Root. The residual limb is 3D scanned and then a matching prosthetic limb is designed to match. It is printed with laser sintered titanium and is available in different colours. A video of FitSocket in operation can be seen at a video titled *"The FitSocket"*, at https://vimeo.com/93307423

steel, copper-silver, copper-gold, silver-gold, gold-nickel and silver-nickel are said to be possible as well.

The designer has said that other metals such as aluminium, stainless steel and titanium would require more research and a kiln with a controlled atmosphere such as a vacuum or argon gas.

The inventor estimates that postage cost for the unit to Australia is US$300-$400. Note that before you pursue 3D metal printing, you would need to satisfy yourself that the metallurgy of the components produced would be suitable for your application.

See these videos for more details:

- *"3D Printing Metal with the Iro3D Desktop Metal 3D Printer - Solid High Carbon Steel Parts"* – **https://youtu.be/4FkzLs7cLes**
- *"Selective Powder Deposition (SPD) in a nutshell"* – **https://youtu.be/IzIvxROhadw**
- *"Just another 3D printed steel object"* – **https://youtu.be/2C2P5RQUPr**
- The YouTube playlist for this printer can be seen at: **http://siliconchip.com.au/link/aam5**

Aurora Labs

A Perth-based Australian company called Aurora Labs (**https://auroralabs3d.com/**) makes what is believed to be

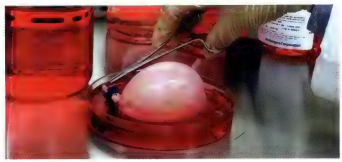


Fig.27: a 3D printed replacement human bladder.

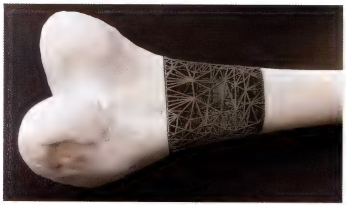


Fig.28: there is a collaborative project between the Australian Government, RMIT University in Melbourne, the University of Technology Sydney (UTS), St Vincent's Hospital Melbourne and the global medical technology company Stryker to produce "just in time" implants to precisely replace a section of diseased bone removed during surgery using a 3D printer. Currently, two operations are required due to the time required to produce the implant. Image credit: RMIT University.

the most inexpensive Direct Metal Laser Melting (DMLM) machine in the world, the S-Titanium Pro, which is priced at US$55,000 (see Fig.34).

The machine can produce layer thicknesses as little as 50 microns with an X-Y resolution of 50 microns and pieces of up to 200mm x 200mm x 250mm can be fabricated. A variety of metals can be printed such as stainless steel, bronze, titanium, Inconel, iron and nickel silicon boron alloys. See Fig.33 for examples of items that can be created by this machine.

The lower cost of Aurora Lab's machines are due to the use of twin CO^2 lasers of 300W total power instead of costly fibre lasers, and also because of the use of an X-Y drive engine to scan the laser across the workpiece instead of a much more expensive galvanometer-based scan engine.

In addition to manufacturing the metal printer, Aurora Labs intends to manufacture metal powders to use in the machines. The supply of powder for 3D metal printing is of particular concern as there is expected to be a worldwide

Fig.30: the envisionTEC 3D-Bioplotter System for biological printing.

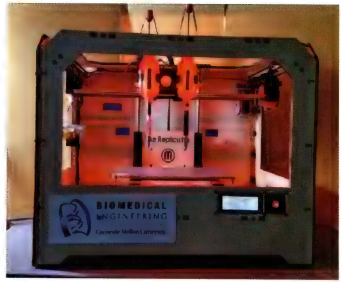


Fig.29: a MakerBot 3D printer modified by Adam Feinberg at Carnegie Mellon University to print 3D biological structures for breast cancer research. The custom-made extruder component that prints hydrogel inks to create the structures was itself 3D printed.

shortage as metal components come to be mass produced by 3D printing in the process known as rapid manufacturing printing (RMP), which requires special high-speed machines.

Aurora Labs also has Rapid Manufacturing Printing machines under development which are twenty times faster than other similar machines and they are expecting to produce machines which are even faster than that. The first beta copies of RMP machines were due to be released toward the end of last year (2018).

Additional attractive features of this machine include the use of open source architecture, so free open source software such as MatterControl 3D printing software can be used.

Also, users of this machine are not restricted to the powder supplied by the manufacturer, as any powder that meets

Fig.31: the iro3d printer which is possibly the lowest-cost 3D metal printer available right now.

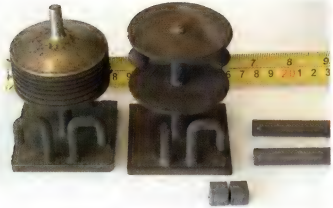


Fig.32: some sample metal components produced with the iro3d printer.

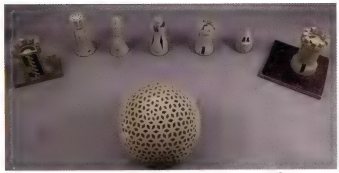


Fig.33: examples of parts printed with Aurora Labs' S-Titanium Pro. Note the detail inside the cutaway chess piece.

Fig.34 [below right]: Aurora Labs' S-Titanium Pro D metal printer.

the manufacturer's specifications can be used. Both of these features make the machine very attractive for smaller users such as smaller engineering firms, university labs and for makers of medical implants.

This machine is not designed to replace $400,000-$500,000 units but is a "stepping stone" machine for organisations starting to 3D print with metal.

Motorcycles

The world's first 3D printed motorcycle is the Light Rider. It is electric, with a top speed of 80km/h, a range of 60km and has an exchangeable battery (see Fig.35). It weighs just 35kg. It is made by the German company APWorks (www.apworks.de/en/). The company plans to make a small number of street legal bikes.

Motor vehicles

Various motor vehicles are now being or have been 3D printed. One such car that will supposedly be available for purchase this year is the LSEV by Italian car maker XEV (X Electric Vehicle; www.x-ev.net/) – see Fig.36. It will be produced in China by the 3D manufacturer Polymaker.

The printing process used is FDM or Fused Deposition Modelling. In contrast to a regular car which typically has about 30,000 components, counting every nut and bolt, this car will have just 57.

The car bodies are printed with Nylon and rubbery thermoplastic polyurethane for the bumpers.

After the car bodies are printed, they go through a process called vacuum lamination in which a coating of 2mm thick Nylon film is put over the car bodies to hide the printed layers. This also eliminates the need for painting.

Parts that are not printed are the chassis and drivetrain, glass and seats.

The car is electric with a top speed of 69km/h and a range of 150km, and it weighs 450kg, which would make it suitable for city commuting and shopping trips.

The company says that the postal service in Italy has commissioned 5000 of the cars and car leasing company ARVAL has ordered 2000. The price is expected to be 10,000 Euro or around A$16,000.

Fig.35: the world's first 3D printed motorcycle. The frame is 3D printed in aluminium and it has an "organic" look, not on purpose but because of the optimisation algorithms which produced this design without human intervention. Humans imposed certain constraints such as component dimensions and computer software then generated the shapes.

Fig.36: the LSEV, the first mass-produced 3D printed car, said to go into production in 2019. See the video titled *"Bringing LSEV to life - The 1st Mass Produced 3D Printed Car"* at https://youtu.be/g4XAy9FIrvk

Fig.38: the 3D printed space frame of the Divergent 3D blade, which is made of aluminium and titanium, with some standard carbon fibre tubing components.

Earlier vehicles

While the LSEV is the first 3D printed car intended for mass production, the first "fully" (with printed chassis) 3D printed cars were the Divergent 3D Blade from 2015 (see Fig.38) and the Local Motors LM3D, also from 2015 (see Fig.39).

Divergent 3D is based in Los Angeles and made the Blade using a variety of 3D printing techniques. It was intended as a technology demonstrator and they hope that other automobile designers will submit their designs to them for manufacture via 3D printing.

The Blade has a 3D printed aluminium and titanium chassis, weighs 590kg with a 2.4l Mitsubishi Evolution X engine which produces 522kW running on petrol or CNG. The driver sits in the middle of the carbon fibre, aluminium and titanium chassis. The carbon fibre components, wheels, engine and certain other components are not 3D printed.

The car has a top speed of around 320kph. You can see a very informative video titled *"2015 Divergent Blade - Jay Leno's Garage"* at **https://youtu.be/vPv7PwS50QE**

The Local Motors (**https://localmotors.com/**) electric LM3D Swim was intended to be put on sale in 2017 for a price of US$53,000 but it does not appear to have gone to market. 75% of the car is 3D printed and it consists of 80% ABS plastic and 20% carbon fibre. It takes 44 hours to print.

You can see a build video titled *"LM3D Swim – Safe. Smart. Sustainable. – 3D printed Car by Local Motors (2015)"* at **https://youtu.be/TKkXRlli-aw**

Fig.40: the URBEE, the first car to have a 3D printed body.

Fig.39: the Local Motors LM3D Swim, another car with a 3D printed body.

One of Local Motors' current offerings is the Olli 3D printed self-driving minibus that can be used in places like university campuses and can be called from a smartphone.

Finally, the URBEE (**https://korecologic.com/**) was the first car with a 3D printed body in 2011 but it used a conventional chassis (see Fig.40). You can view a video titled *"URBEE (1st 3D Printed Car Body)"* at **https://youtu.be/2YOCkd1aJ2c**

Multi-material and multi-colour 3D printing

The Palette 2 from Mosaic (**https://www.mosaicmfg.com/**) is a device that splices pieces of filament of various lengths and colours together and feeds them to a standard 3D printer in a particular order. This allows many common 3D printers to print multi-colour and multi-material objects (see Fig.41).

Nano-scale 3D printing

3D printing concepts can be applied at the ultra-small scale as well. Structures such as microbatteries, microelectronic, microfluidic, micro-optical and biochip components can be produced with a variety of materials such as metals and polymers (see Figs.42-46).

Making 3D objects from mobile phone pictures

It is possible to use your mobile phone or another camera to take multiple pictures of an object from different angles and use software on a computer to construct a 3D image

Fig.41: an example of a multi-colour object printed from a standard 3D printer using filament that has been spliced together by Palette 2.

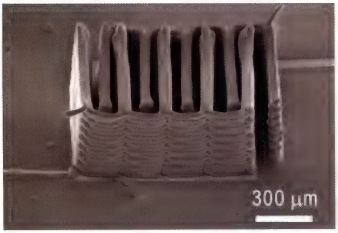


Fig.42: a team at the Wyss Institute at Harvard University and the University of Illinois at Urbana-Champaign produced this lithium-ion microbattery measuring about 1mm across using nano 3D printing techniques. After these electrodes (made of electrically conducting ink) were deposited, the device was filled with electrolyte and encapsulated.

of the object of interest. You can then 3D print a copy of that object.

The following video shows how to do this with free software. It is titled *"Photogrammetry - 3D scan with just your phone/camera"* and can be viewed at https://youtu.be/ye-C-OOFsX8

This next video shows a different technique which requires a CUDA-enabled graphics processor (GPU). It is titled *"How to 3D Photoscan Easy and Free!"* and is viewable at https://youtu.be/k4NTf0hMjtY

It shows how to construct a 3D model but does not show how to 3D print it. Several 3D scanning Apps for phones are available, both free and paid for, some of which can produce files for printing and others which require extra work to do so.

Phlat printer

The PhlatPrinter is an open source home-built CNC (computer numeric control) machine that can cut large sheets of foam to make model aircraft and other sheet materials such as wood and MDF. It can be used to make many other 3D items from sheet materials. For further details, see: www.phlatforum.com and https://openbuilds.com/builds/phlatprinter-mk-3.5207/

Fig.44: screws and nuts with threads of 1.3mm outer diameter, printed with a Nanoscribe Photonic Professional GT.

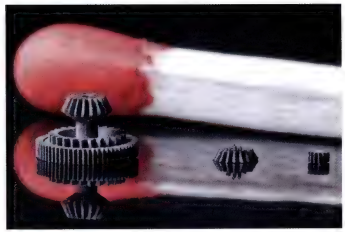


Fig.43: microscopic metal parts 3D printed using laser sintering by the company 3D microprint (www.3dmicroprint.com/)

RepRap

The RepRap is a low cost, open source 3D printer that can print some of its own parts, making it partially self-replicating. It was voted the "most significant 3D printed object" in 2017. Users are encouraged to make variations on the initial design so many have been created. https://reprap.org/wiki/RepRap

Vat polymerisation printers for hobbyist use

There are a number of vat polymerisation (resin) printers now available for hobbyist use.

Two low-cost printers that one website rated highly are the Peopoly Moai (https://peopoly.net/), which they rated as "best value", and the Anycubic Photon (http://www.anycubic3d.com/), which they rated as the "best budget resin 3D printer".

The Peopoly is available as a kit in the USA for US$1295 or fully made for US$1995 while the Anycubic can be purchased in Australia from eBay for upwards of A$550 plus postage. SC

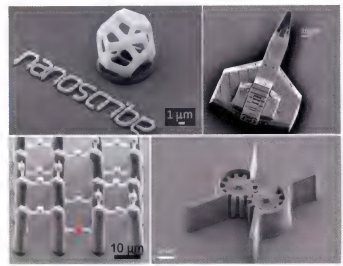


Fig.45: some examples of nano 3D printed components made with the Nanoscribe Photonic Professional GT system. Note that 1µm is 1/1000 of 1mm. Image courtesy of Dublin City University Nano Research Facility.

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Any 2 for $24

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All heat & no flame!

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Great for moving UNO based designs & code into e-textile projects.

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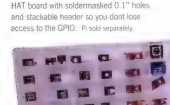

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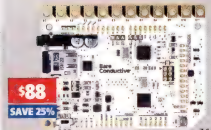

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A WORLD-FIRST DIY PROJECT FROM SILICON CHIP

DAB+ TUNER

Digital Audio Broadcasting with FM & AM and a touchscreen interface!

By Duraid Madina and Nicholas Vinen

We believe this is the first build-it-yourself digital radio published in any magazine – certainly here in Australia, if not the world. It receives, as you would expect, DAB+. It also receives FM (mono/stereo). But (again to our knowledge!) this is THE FIRST to also receive AM radio (not many, if any, commercial DAB+ receivers can do that!) It's simple to use, thanks to the 5-inch touchscreen and graphical interface provided by the powerful Explore 100 processor. It has many audio output options and offers outstanding sound quality, too.

This is, without doubt, the most capable build-it-yourself radio design ever published – anywhere!

It can receive DAB+ digital radio in stereo, FM in mono or stereo and AM in mono. It also has a really intuitive colour touchscreen graphical user interface (GUI) and lots of other great options such as remote control, headphone and speaker outputs, digital audio outputs and more.

You just need to glance at the features and specifications to get an idea of how comprehensive this design is.

We've tried to take advantage of all the features of the digital radio receiver IC that we've used, as well as the GUI

capabilities of the Explore 100 module, to make the user interface experience as smooth as possible.

The radio incorporates an onboard headphone amplifier with digital volume control, so you can plug headphones or earbuds straight in. There's also a small onboard stereo power amplifier, with decent sound quality, allowing a pair of passive speakers to be driven at up to two watts per channel.

In AM and FM modes, you also have the option of using one of the digital outputs (S/PDIF or TOSLINK) to feed audio to a hifi receiver or DAC.

The radio incorporates a ferrite rod antenna for AM but an external AM loop antenna can also be used, for better reception.

To receive FM and DAB+ broadcasts, an antenna is connected to the SMA socket. This can be a proper roof-mounted VHF antenna, or a telescopic whip attached directly to the side of the radio.

As well as using the intuitive touchscreen interface, you can also control major functions such as changing channels, modes and volume via an infrared remote control.

You can easily enter station frequencies if you use a remote control with a numeric keypad.

The whole thing is powered off 5V, so you can use a standard plugpack. You can even use a USB power bank, making the radio fully portable.

We've also made the design upgradeable in future, so that internet radio could potentially be added using a WiFi "daughter board". The whole thing is housed in a custom laser-cut acrylic case.

Design challenges

We've been working on this radio design for more than six months. There are several reasons that it has taken so long, besides the fact that it is an ambitious project.

For example, there is little publicly available information on the main chip, the Si4689 radio receiver IC. And some of the information that we found turned out to be incorrect.

We bought a development kit to get the chip up and running initially, which included the firmware needed for that chip to operate, along with information on how to configure it.

We then had to develop MMBasic software to drive that chip, along with other parts of the circuit such as the serial flash (which is used to store firmware), the digital audio transceiver and so on.

We had hoped to produce a radio which could also receive Digital Radio Mondiale (DRM), the long-range digital radio broadcasting standard.

This is not yet available in Australia but there are DRM stations in New Zealand and we figured that one day, we would get it too.

Unfortunately, while the Si4689 supports DRM in theory, the firmware supplied does not have a DRM mode. The hardware as presented supports DRM reception but we don't know if or when firmware will be released to enable it.

For more information on DRM, see our articles in the November 2013 (siliconchip.com.au/Article/5448) and September 2017 (siliconchip.com.au/Article/10798) issues.

Another unfortunate limitation has to do with the Si4689's digital audio output. Our board has support for converting the digital data to both common consumer formats – S/PDIF and TOSLINK – so you can feed it to a DAC or receiver. But again, the firmware lets us down, as it disables the digital output in DAB+ mode; something not mentioned in any of the documentation.

So we can only guarantee that the digital outputs work in the AM and FM modes. That may be fixed in a future firmware update, but we can't say when that might happen.

We are guessing that the digital output is disabled in DAB+ mode due to concerns over users making copies of the audio data.

Regardless of those problems, this is still a very capable radio. And it can be easily upgraded in future if any of the above firmware gremlins are resolved.

Surface-mount components

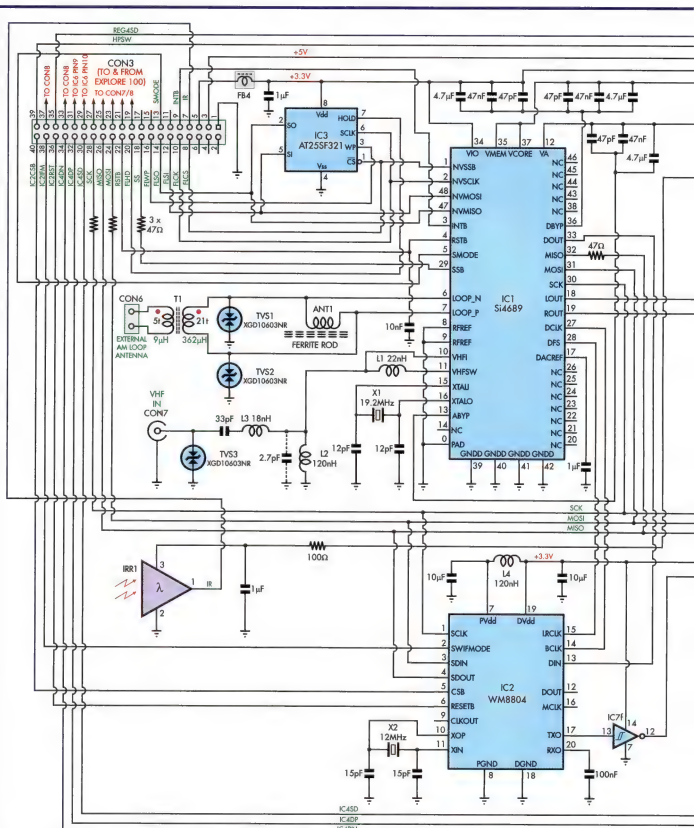
The Si4689 radio chip has many great features and there really aren't any equivalent chips available, so it's the obvious choice for this project. But it's only available in a 48-pin QFN (quad flatpack no leads) package.

The "no leads" part of its name may give you a hint that this is not a particularly friendly package for hand-soldering.

Having said that, we succeeded in soldering two of these chips by hand (out of two that we tried), using two

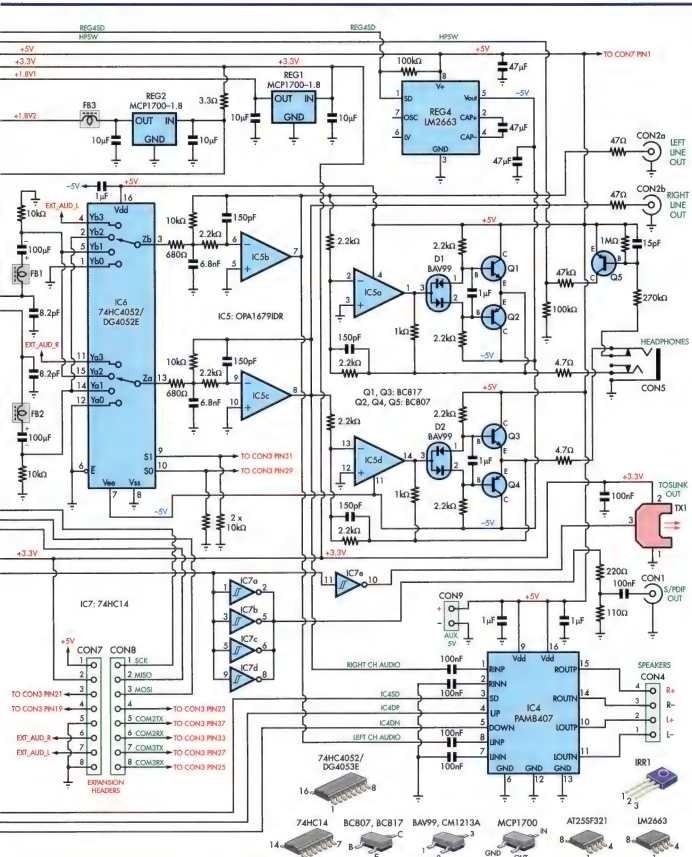
Features

- DAB+, FM and AM reception
- Eight favourite station presets per mode
- 5-inch colour touchscreen interface
- SMA socket for external FM/DAB+ (VHF) antenna or telescopic whip
- Internal AM antenna (ferrite rod) plus terminals to connect external loop antenna
- Stereo line outputs, headphone driver and onboard stereo audio amplifier
- Digital audio outputs (S/PDIF and TOSLINK)
- Digital volume control, with separate settings for line out/headphones and speakers
- Signal strength reported in all modes
- AM/FM modes report signal-to-noise radio (SNR); DAB+ mode reports error count
- Optional infrared remote control
- Auto-mutes speakers when headphones are plugged in
- Stereo amplifier can drive two 4-8Ω speakers at 1W+ each
- FM RDS/RBDS decoding
- Automatically scans for channels (services) in DAB+ bands
- Channel name and currently playing program displayed
- Upgradeable firmware
- Possibility for future expansion (eg, WiFi internet radio support)
- Powered from 5V DC regulated plugpack
- "Quiet" mode for AM reduces digital pickup
- DAB+ frequencies default to Australian channels
- Optional laser-cut acrylic case



DAB+/FM/AM DIGITAL RADIO RECEIVER

Fig.1: at the heart of this radio board is IC1, the Si4689 digital radio receiver IC. Its crystal oscillator timebase and antenna matching components are shown to its left, with the analog audio switching and filtering parts to its right. The digital audio processing chip (IC2), expansion headers and audio amplifier (IC4) are arrayed along the bottom of the diagram, with the serial flash chip (IC3) and power supply components along the top.



Be sure to read next month's article on the DAB+/FM/AM Radio for construction details, as well as a special offer. We will be producing a limited run of radio PCBs with the tricky parts (IC1 and some associated components) pre-soldered, making the assembly substantially easier for you.

Specifications

- Power supply: 5VDC (regulated) @ 2A
- AM tuning range: 520-1710kHz
- FM tuning range: 76-108MHz
- DAB+ tuning range: 168-240MHz (suits Australia, New Zealand and rest of world using DAB+ standard)
- Line level outputs: 2 x 775mV RMS (–11dBm)
- Headphone output power: ~20mW into 32Ω, ~40mW into 16Ω, ~80mW into 8Ω (can be increased)
- Speaker output power: 1-2W (depending on speaker impedance and power supply)

different techniques. So it isn't as difficult as you might think

But you will definitely have a better chance of success if you already have some SMD soldering experience.

Since the key part is an SMD, and since the Explore 100 which we're using to drive the radio also involves a few SMDs, we figured that the remainder of the parts might as well be surface-mounting types too.

Actually, for the critical parts required by the Si4689 IC, we really don't have a choice since through-hole parts would be too large to get close enough to the radio chip for good RF performance, and many of those parts would not be available in through-hole packages anyway.

The good news is that where possible, we've used larger and easier-to-solder parts, meaning that once you've gotten the Si4689 and its surrounding components in place, the remainder of the board is not too difficult to assemble.

We'll give detailed instructions on how to successfully solder the tricky parts in this project in a future article. We are also planning to get the more difficult parts pre-soldered to a batch of PCBs and then make these available to our readers who would prefer to avoid the trickier parts of the build – more details next month!

Circuit description

The full circuit of the radio, except for the components mounted on the Explore 100 module, is shown in Fig.1. It's based around IC1, a Si4689 digital radio receiver IC.

The board containing all the components shown on Fig.1 piggybacks on the Explore 100 module and the two are connected via 2x20 header CON3. This carries both control signals from the Explore 100 and also power for the radio circuitry.

IC1 requires relatively few components to operate and these can be broken down into a few categories: antennas and matching networks, a crystal oscillator, supply bypass capacitors, a serial flash chip used to store its firmware and audio filter circuitry.

Antennas & matching networks

AM signals are picked up either by an external loop antenna connected across terminal block CON6, or via an onboard ferrite rod antenna. The external antenna (if fitted) is connected in parallel with the ferrite rod via a small 1:6 turns ratio transformer wound on a ferrite core.

This is necessary since the external antenna will typically have an inductance in the range of 10-20µH while IC1 expects an inductance in the range of 180-450µH, as is typical for a ferrite rod.

We couldn't find any source of prewound transformers but found it was quite easy to wind one using standard parts. The instructions for doing so will be in a subsequent article.

Ideally, you should use an external antenna for AM since the ferrite rod, being relatively close to the digital circuitry, inevitably picks up some noise and will only work well if you have a strong signal.

Transient voltage suppressors

TVS1 & TVS2 are low-capacitance devices that do not affect the RF signal but will conduct to protect IC1 from electro-static discharge and lightning-induced energy.

That is provided that the lightning strike is not too close; it certainly will not do much if there is a direct strike on the antenna!

The Silicon Labs literature suggested using a single CM1213 dual diode clamp rather than TVS1 & TVS2 but we found that these reduced the received RF signal strength whereas the XGD-series polymer clamps do not.

The AM antennas are both connected between the AM dedicated pins on IC1, LOOP_N and LOOP_P.

FM and DAB+ reception use a different, VHF antenna. This is connected via CON7, which can be either an SMA connector (as on our prototype) or a PAL connector, which is difficult to find these days, but we have a source.

You can use an extendable whip-type antenna, a rooftop antenna, or any other antenna suitable for the relevant frequency range, ie, 88-206MHz.

The same transient voltage suppressor device is fitted to CON7, again for ESD and lightning protection of the main chip. The recommended CM1213 had an even more drastic affect on FM/DAB+ signal strength so again, we have used a polymer clamp ,TVS3.

The signal is fed into IC1 via a matching and tuning network (mostly as per the data sheet), to the VHFI pin on IC1 (pin 10).

While developing this circuit, we ran into some differences between the recommendations in the SiLabs literature and their actual implementation of the circuit, in the form of the demonstration/development board. One of the differences is that the 2.7pF capacitor is recommended in the literature but not fitted on the demo board.

We left it out of our final prototype, with no apparent ill effects. Hence the dotted connections shown in the circuit diagram. We suggest that constructors leave this part out, but we left its pads on the PCB in case it is needed.

The VHFSW pin (pin 11) of IC1 is pulled to ground when the radio is in DAB+ mode. This connects 22nH inductor L1 in parallel with the 120nH inductor, re-tuning the matching network to better suit the higher DAB+ frequencies (203-206MHz), compared to FM (88-108MHz).

All of the FM/DAB+ matching components are carefully chosen small SMDs placed close to IC1 and in a line between it and CON7. This minimises signal loss from parasitic effects such as PCB track capacitance and inductance.

Crystal oscillator

A high-precision 19.2MHz crystal is connected between pins 15 and 16 of IC1 and this is used both for tuning and to provide clock signals for the internal digital circuitry in IC1. The crystal we're using has a specified load capacitance of 18pF but we are using two 12pF load capacitors, since IC1 also has software-programmable load

capacitance on those two pins.

By using lower-than-specified value load capacitors, we were then able to program the tuning capacitors within IC1 to get the crystal frequency very close to nominal.

Bypass capacitors

IC1 has four supply pins: V_{IO}, which defines the external I/O pin voltage levels, V_{CORE}, which powers its digital circuitry, V_{MEM}, which powers its internal memory and V_A which powers its analog RF circuitry.

All of these are designed to run at 1.8V but V_{IO} can go as high as 3.3V. Since the Explore 100 has 3.3V I/Os, we decided to run V_{IO} at 3.3V too, allowing the two chips to communicate without signal level translation.

All four rails have three bypass capacitors each, ranging in value from 47pF to 4.7μF. The 47pF capacitors are physically smaller than the others and located right up near the IC.

The reason for this is that low-value, physically small capacitors have a very high resonant frequency and keeping them close to the IC minimises the parasitic inductance of the tracks.

Therefore, these small capacitors are very effective at bypassing very high-frequency signals, while the larger capacitors provide bulk bypassing at lower frequencies. The combination gives each supply rail a very low impedance from DC up to around 4GHz.

This is important since IC1 contains a PLL (phase-locked loop) which includes a VCO (voltage-controlled oscillator) that runs at between 2.88GHz and 3.84GHz.

Good bypassing on the supply pins is essential both for proper operation of the VCO and other internal circuitry, and to prevent this VCO from "leaking out" of the chip and being radiated into the surrounding environment (and possibly also interfering with radio reception).

This is also why we have four ferrite beads in the circuit. FB1 and FB2 (along with the 8.2pF capacitors from the audio outputs to ground) shunt any VCO signals present at the audio outputs to ground, so that these signals cannot be radiated from the tracks and audio circuitry.

Similarly, FB3 and FB4 prevent leakage of any high-frequency signals which may make their way back out of the supply pins from getting very far away from the IC, where the supply tracks may become antennas. Again, these ferrite beads have been carefully selected to be effective at suppressing the range of frequencies that we're concerned about.

Serial flash chip

IC3 is a 32Mbit serial flash chip which runs from a 3.3V supply and can operate at up to 104MHz. IC1 requires a 512KB firmware image to be loaded into the chip for each operating mode, ie, AM, FM or DAB+.

So we need to provide it with a minimum of 1.5MB (12Mbit) of firmware for the radio.

This firmware can come from the Explore 100 but loading it this way is quite slow – it takes a few seconds.

Since it's annoying to have to wait several seconds to change radio modes, we instead use the Explore 100 to load the firmware into IC3 before the radio is first used.

It's read off the SD card and then fed to serial flash chip IC3 via a dedicated SPI interface on pins 8, 10, 12 and 14 of CON3. These are not connected to either of the Explore 100's hardware SPI ports, so they are controlled via

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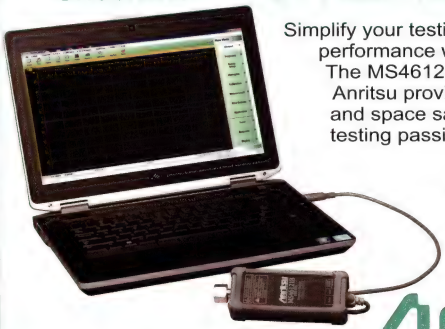

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software. We have written a CFUNCTION to communicate over those pins using SPI since it was too slow in MMBasic.

While IC1 supports programming flash chips, its support is quite limited and IC3 has write-protect features which IC1 cannot handle. Hence, we have to program it separately in this manner.

The SPI bus on the aforementioned pins of CON3 also connects directly to IC1, to pins 1, 2, 47 and 48, so it can read the firmware off the flash chip; hence we only drive those pins while IC1 is in reset, before it has started operating.

Once the firmware is stored in IC3, IC1 can load it very quickly on request, so it takes less than one second to change radio modes. And unless you want to upgrade the firmware in future, you only need to load it into the flash chip once.

The only extra component required for IC3 is its 1µF supply bypass capacitor. It has two extra control pins: $\overline{WP}$ (pin 3), which can be used to prevent modification of the contents of the flash, and $\overline{HOLD}$ (pin 7), which is used to pause SPI communications temporarily.

We don't really need these functions but the pins are connected to the Explore 100 header anyway (at pins 16 and 20 respectively).

The Explore 100 can then set its digital outputs to a high level to disable these functions. This gives us the flexibility to modify the software to use them in future if it ever becomes necessary.

After all, the Explore 100 has plenty of free I/O pins and it's easier to program these pin states in software, rather than to tie them to GND or 3.3V and then have to re-make the board if we make a mistake

Audio switching and filtering

Analog audio from radio chip IC1 appears on pins 18 (left channel output) and 19 (right channel output). As recommended in the Silicon Labs literature, we have 8.2pF filter capacitors connected between these pins and ground, plus series ferrite beads close to the chip.

This is necessary because signals from the high-frequency internal PLL may "bleed out" through these pins and radiate back to the antenna(s) and radio input circuitry. This filtering does not affect audio signals but eliminates any RF components which may be present.

The Si4689 has internal volume control, so we don't need to provide an external volume control for the line outputs or headphone amplifiers.

The audio signals are AC-coupled via two 100µF electrolytic capacitors to remove the half-supply DC bias which is present, then fed to the input pins of IC6, a dual four-way analog multiplexer. It's controlled by the Explore 100, via pins 29 and 31 at CON3.

Its default state, set by the pull-down resistors on the S0 and S1 pins, is for the left and right channel audio sources to come from pins 1 and 12. These are connected to ground, so by default, the analog output is muted.

The Explore 100 must drive one of the S0/S1 pins high for the audio from IC1 to be fed through, and if S1 is high, the left and right channels are swapped.

If both S0 and S1 are driven high, the audio source instead comes from expansion header CON7. So if we later develop, say, an internet radio module that plugs into CON7/CON8, the Explore 100 can be programmed to feed its audio through to the outputs when it is activated.

The audio signals which have been selected by IC6 are fed through to op amps IC5b and IC5c, which provide 23.35dB of gain (14.7 times) and also operate as third-order low-pass filters to remove any supersonic DAC switching artefacts from the audio signals.

The gain is quite high because the audio signals eminating from IC1 are low in level – only about 50mV RMS. The filter's -3dB point is 33.6kHz, resulting in a loss of less than 0.5dB at 20kHz, the upper threshold of human hearing.

It's a Butterworth type, for a flat passband, hence the minimal loss within the audible frequency range but it's still good at eliminating supersonic signals.

We've used a multiple-feedback type filter, rather than a Sallen-Key type because it is more effective at filtering out signal frequencies well above the bandwidth of the op amp being used. It is therefore more suitable for getting rid of the very high-frequency artefacts which are typical of delta-sigma type audio DACs.

You can get frequency response, Bode plots and other data on this type of filter at the following website: http://sim.okawa-denshi.jp/en/OPtazyuLowkeisan.htm

We've kept the impedances of the components in the filter relatively low, to reduce the chance of any digital interference being picked up there.

Headphone drivers

The filtered audio signals are fed to dual line output RCA socket CON2 via 47Ω isolating resistors, to prevent any capacitance on these outputs from destabilising the op amps. They're also fed to the other two op amps in the quad package, IC5a and IC5d, via 2.2kΩ resistors.

These operate as headphone drivers, in conjunction with transistors Q1-Q4, which boost the output current capability.

The outputs of IC5a and IC5d (pins 1 & 14) are connected to the headphone socket directly via 1kΩ resistors, which helps to linearise the headphone amplifier, but these outputs also drive transistors Q1-Q4 via dual diodes D1 and D2.

The purpose of these diodes is to bias the output transistors into conduction, so that there is always some current flowing through both (the quiescent current).

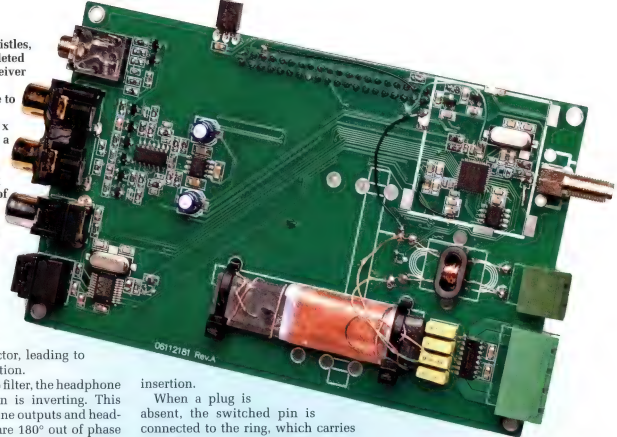
In the case of D1, Q1 and Q2, current flows from the +5V rail, through a 2.2kΩ resistor, then both diodes in D1, through another 2.2kΩ resistor and then to the -5V rail.

The current through these diodes is approximately 2mA, resulting in a forward voltage of around 600mV per diode, or 1.2V total. That 1.2V is also across the bases of Q1 and Q2, so they are biased with around 600mV each.

That's enough to bring them into conduction, resulting in a flow of around 5mA per transistor pair from the +5V to the -5V supply. Therefore, there is little to no "crossover distortion" as the audio signal crosses the 0V point.

A 1µF capacitor between the transistor bases keeps this bias more constant as the output swings away from 0V, despite the changing current through the bias resistors.

The headphones are driven through 4.7Ω resistors, again to isolate any capacitance at the output from the op amps. The values are lower because headphone impedances tend to be low, so higher value resistors would reduce the volume and also reduce



To whet your whistles, here is the completed DAB/FM/AM receiver prototype PCB shown very close to life size (actual board size is 135 x 84mm). For such a huge circuit diagram, there is virtually nothing on the rear side of the PCB except the Explore 100 connector socket seen top centre.

the damping factor, leading to increased distortion.

Like the audio filter, the headphone amplifier section is inverting. This means that the line outputs and headphone outputs are 180° out of phase but it's difficult to think of any reason why that would cause any problems. 150pF capacitors connected across the 2.2kΩ feedback resistors help to stabilise the headphone drivers despite the extra phase shift from the buffer transistors.

While the headphone driver section has no gain, most headphones/earphones are sensitive enough that a few hundred millivolts is all that's required.

If you have headphones which need a much higher voltage swing, you could increase the 2.2kΩ feedback resistor values to say 4.7kΩ (to get 2.1 times gain) or to 10kΩ (to get 4.5 times gain). We don't suggest you go any higher than 10kΩ since maximum volume with 4.5 times gain would be approaching the maximum swing of around ±4V (2.8V RMS) that the circuit is capable of.

Headphone plug insertion detection

The extra components connected to the headphone socket, including Q5, are to detect when headphones/earphones are plugged into the socket, so that the speaker outputs will be automatically muted.

These are necessary because the connector only switches the signal pins when a plug is inserted, so we need to be a bit tricky to sense the plug insertion.

When a plug is absent, the switched pin is connected to the ring, which carries the right channel audio. Since the audio signal voltage is normally well below the 5V supply, that means that current can flow from the base of PNP transistor Q5 and through the 270kΩ resistor to the switch contact and so transistor Q5 is switched on.

Current can therefore flow from the +5V supply, into its emitter and out of its collector, and through a 47kΩ/100kΩ voltage divider, producing a ~3.3V signal. This goes to pin 39 on CON3 ("HPSW"), and on to the Explore 100, to be interpreted as a high level, indicating that the headphones are not plugged in.

When headphones are plugged in, this connection is broken and so Q5's base is pulled up to the +5V supply by the 1MΩ resistor, switching Q5 off. The HPSW signal is pulled down to 0V by the 100kΩ resistor, and this is sensed as a low level by the Explore 100.

The 15pF capacitor prevents RF or EMI pick-up across the 1MΩ base-emitter resistor from switching Q5 on in this condition.

The reason for the use of relatively high resistor values is to prevent this circuit from loading the headphone amplifier and introducing distortion.

Audio amplifier

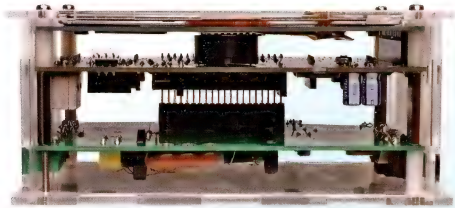
The same filtered audio signals that are fed to the line outputs and headphone amplifier also go to power amplifier IC4. This device (PAM8407) runs off 5V and can deliver about 2W to a pair of 4Ω speakers, or about 1W to 8Ω speakers, with reasonably low distortion (below 0.1%).

It also has an internal digital volume control, activated via pulses delivered to pins 4 (UP) and 5 (DOWN), plus a shutdown pin at pin 3 which allows the amplifier to be switched off, saving power and muting the speakers. This is activated when headphones are inserted, both to save power and to provide the required muting.

This chip was chosen because it is delightfully simple but can deliver reasonable power and without the hassles of a Class-D amplifier (eg, the risk of EMI affecting the radio receiver). It has differential inputs but the inverting inputs are simply terminated to ground with the same value (100nF) coupling capacitors that are used to feed audio to the non-inverting inputs.

Its volume/gain is programmable in 32 steps from -80dB to +24dB. This is controlled via pulses fed into pins 3 and 4 from the Explore 100 via CON3 pins 32 and 34, while the shutdown function goes to pin 30 of CON3. It defaults to 12dB gain on power-up or after the chip it shut down.

At power-up or when the headphones are unplugged, the software



This photo shows how the PCBs are "stacked" within the clear acrylic case, designed to suit the DAB+/FM/AM Radio. The radio board is at the bottom of the stack, upside down. It plugs into the Explore 100 control board, with the LCD touch screen at the top. Construction details, along with the parts list, will be presented next month.

running on the Explore 100 mutes the audio (using IC6) and then sends however many up/down pulses are required to set IC4's volume to the desired level, before unmuting the audio.

There are two advantages to IC4 having its own volume control, separate from IC1. One is that it makes it easy for the user to choose comfortable volume levels for both the headphones and speakers.

As soon as you unplug the headphones, IC4's volume is set to the desired speaker volume level before audio is applied to the speakers. And when you plug the headphones back in, the volume on the socket is already suitable for headphone listening; IC4 is simply shut down as soon as the software notices that the headphones have been plugged back in.

The second advantage is that IC4 provides enough gain to get plenty of volume from the speakers (assuming they have reasonable efficiency) even if the audio signals from IC1 are relatively quiet.

However, there is a limit to how low you can set the headphone volume before the maximum speaker volume is reduced. So it's a bit of a balancing act.

We didn't fit any speakers in the Radio itself, to keep it compact; instead, it has a 4-way pluggable terminal block (CON4), which is externally accessible, to make it easy to wire speakers up and plug/unplug them as required.

Digital audio interface

In some modes, the Si4689 can be programmed to produce I^2S format digital audio data as well as analog audio. This digital data appears in serial format at the D_{OUT} pin (33), which is fed to digital audio transceiver IC2, along with the corresponding clock signal (D_{CLK}, pin 27) and framing signal (D_{FS}, pin 28).

IC2 is a Wolfson WM8804 which converts between I^2S and S/PDIF formats. It's controlled by the Explore 100 over the same SPI bus as the Si4689, except that it has a separate chip select line ($\overline{CSB}$, pin 5) which is driven from I/O pin 40 on CON3. IC2 also has a reset pin, pin 6, which is driven from pin 36 of CON3, plus a mode control pin (SWIFMODE, pin 2), wired to pin 38 of CON3.

The Explore 100 sets up the interface mode pin during its start-up sequence, then releases reset and sends SPI signals to IC2 to configure it to operate as an I^2S to S/PDIF translator.

IC2 uses a separate 12MHz crystal for its timebase. It can use a variety of frequencies but we decided to use the frequency suggested in the data sheet.

When valid I^2S data is being produced by IC1, an S/PDIF data stream appears at pin 17 of IC2 (TXO) and this is buffered by schmitt trigger inverter IC7f.

Its output pin 12 then feeds the signal to the input of another inverter, IC7e (pin 11) and its output feeds the input of TOSLINK transmitter TX1. This provides the optical digital audio output.

The same signal from IC7f is also inverted by the four remaining inverters in the hex package, IC7a-d, which are wired in parallel to increase drive strength. That's because these inverters drive the S/PDIF coaxial output, CON1, via a 220Ω/110Ω resistive divider and 100nF AC-coupling capacitor, to remove the DC bias from the signal.

This arrangement is used to obtain the correct output voltage (about 0.5V peak-to-peak) and source impedance (about 75Ω) to suit the S/PDIF standard. A 75Ω coaxial cable can be wired from CON1 to the S/PDIF input on a DAC or home theatre receiver, which will internally terminate the signal with a 75Ω load. You need to keep that in mind when calculating the voltage at CON1.

Infrared receiver

All of the Radio's functions are controllable using the Explore 100's 5-inch colour touchscreen, but in case that isn't enough, we've also included an infrared remote control receiver, IRR1.

It's powered from a filtered 3.3V supply rail and its output signals are fed to pin 7 of CON3, the designated infrared receiver input pin of the Explore 100.

MMBasic can therefore receive and decode standard infrared protocol commands and pass them on to the BASIC software.

As a result, you can use a universal remote to change modes, channels, input frequencies, adjust the volume, mute, switch the radio into and out of standby mode and various other functions. The full list of remote control commands will be described in a later article.

Power supply

The radio runs off a regulated 5V DC supply which is fed into the Explore 100 board, and then onto the radio board via pin 3 of CON3. This powers the audio amplifier (IC4) directly, as well as op amp IC5 and the headphone amplifier transistors.

As mentioned earlier, the Si4689 radio IC (IC1) has four supply pins: $V_{I/O}$, V_{MEM}, V_{CORE} and V_A. For compatibility with the Explore 100, we are using 3.3V for $V_{I/O}$, which is drawn from pin 5 on CON3 after passing through a ferrite bead to prevent EMI from radiating back from the radio chip into the Explore 100 board.

V_{MEM} and V_{CORE} are powered from one 1.8V rail, derived from the 3.3V supply by REG1, a 1.8V low-dropout linear regulator.

V_A is used to power IC1's internal PLL and its stability is critical, so this supply is fed from a separate but

identical regulator, REG2.

All three supplies are extensively decoupled, as recommended by Silicon Labs.

A switched capacitor inverter IC (REG4, LM2663) generates a -5V rail from the +5V supply, both of which are fed to the op amps and headphone amplifier.

This has three benefits over using a single-ended 5V supply:

One, it provides more than double the potential signal swing for driving headphones;

Two, it allows us to use op amps with lower distortion and noise; and

Three, it means we don't need to apply a DC bias to the various audio signals in our analog circuitry, eliminating the possibility of supply noise injection.

REG4 has a shutdown pin (SD) which is wired to pin 35 of CON3; however, REG4 needs to be kept powered most of the time to prevent DC voltages from appearing at the analog audio outputs.

But the SD pin is used, because we found that if REG4 was left enabled at power-up, it could "latch up", drawing a lot of current without actually producing a -5V output.

The solution is to tie the SD pin high, to +5V, via a 100kΩ resistor so that REG4 is shut down initially. Then, after the Explore 100 "boots up", we wait a short period for the 5V rail to stabilise before activating REG4. That solves the latch-up problem.

Like IC1, digital audio transceiver IC2 also has an internal PLL and this is powered from the P_{Vdd} pin, but it must be the same voltage as the D_{Vdd} pin, which is 3.3V in this case.

For stability, we have isolated the two supplies using a low-value inductor and this forms a low-pass filter with the 10µF bypass capacitor, helping to smooth out the PLL operation.

Expansion headers

We briefly mentioned CON7 and CON8 earlier. We thought that at a later date, it might be a good idea to add internet radio capability using an ESP-01 (or similar) WiFi module and some extra processing circuitry.

CON7 and CON8 are provided for such a board to plug into. Power is supplied to the add-on module in the form of 5V DC between pins 1 and 8 of CON7, and 3.3V DC at pin 2 of CON7.

The Explore 100 can control the ESP-01 and any other devices on the add-on board using two bidirectional serial ports (pin 5-8 of CON8) and/or SPI (pins 1-3 of CON8, with pin 4 of CON8 or pins 3/4 of CON7 used for chip select).

Audio can be fed back into the radio board via pins 6 and 7 of CON7, which are connected to the spare inputs of multiplexer IC6, with a signal ground on pin 5.

Finally, pins 3 and 4 of CON7 and pin 4 of CON8 provides some general-purpose digital I/O lines which may be used to control aspects of the add-on board (eg, power up and down); as mentioned earlier, one or more of these may also be used as chip select lines for the SPI interface.

Coming next month

That's all we have room for this month. Next month we will present the parts list and PCB overlay diagram, show more photos of the final prototype PCB and describe in detail how to assemble the board.

A third article will then describe the software operation, final assembly and how to use the radio. SC

A QUICK PRIMER ON STEPPER MOTORS

BY JIM ROWE

Stepper motors are used in all kinds of electromechanical devices including hard disk drives, CD players, CD/DVD/Blu-ray drives and players, plotters, engraving machines, laser cutters and printers (including 3D printers). This article explains how they work and how to use them.

A **stepper motor or stepping motor** is essentially a brushless DC motor that's designed to rotate its shaft in discrete steps rather than continuously.

Each step is made in response to a sequence of current pulses fed through adjacent pairs of electromagnet coils, with each pair wound on opposite sides of the stator assembly.

If no further pulses are applied, the rotor will remain in the new position but if another sequence of pulses is applied, it will make a further step. And if further pulse sequences are applied, it will continue stepping.

A significant advantage of stepper motors is that they can be made to rotate the rotor shaft through a defined angle without the need for positional feedback. As a result, they are often used in "open-loop" control systems, where the position of an object like a printer head needs to be accurately controlled but without requiring the added cost of a full-scale closed-loop servo system.

Another advantage of stepper motors is that they can be made to rotate the rotor in either direction by merely changing the pulse sequence fed to the pairs of stator coil windings. They have a fair bit of torque, including while stationary, and if they have no gearing, there's no backlash. So they are useful in applications where they need to resist movement from external forces, including gravity.

Where fine control is necessary, it is possible to "microstep" a stepper motor, which allows very fine control over the shaft's position, with steps less than 1°. Because that is done without gearing, there is minimal backlash or risk of inaccuracy due to gear slop.

Stepper motors have not been around as long as the more familiar brushes-and-commutator type of DC motor, or either the synchronous or induction type of AC motor.

Stepper motors were invented in 1965 by Morton Sklaroff, an engineer working for US firm Honeywell Inc. They started to appear at the beginning of the "digital era".

Since the late 1960s, they've become widely used, especially in applications involving both digital electronics and electromechanics.

They're now made in large numbers and in a wide range of shapes and sizes, from subminiature sizes designed to drive the optical head leadscrew of CD/DVD/Blu-ray disc drives, all the way up to much larger and higher-torque units capable of driving actuators in CNC machinery.

Types of stepper motors

Nowadays there are three common types of stepper motor, known as the "permanent magnet stepper", the "variable reluctance stepper" and the "hybrid synchronous stepper".

The hybrid type is the most common; it is essentially a combination of the other two types and provides maximum torque and power in the smallest physical size. This is the type we're mainly going to cover here.

Even within the hybrid stepper family, there are various configurations regarding the number of pairs of stator poles and windings.

Some have two phases (ie, two pairs of stator poles and windings) while others may have three or four phases. Very large steppers may even have five phases, ie, a total of 10 stator poles and windings.

The most common steppers have the minimum configuration of two phases and hence four stator poles and windings.

Inside a hybrid stepper

Two important characteristics of a hybrid stepper motor are that it has a rotor with an axially polarised permanent magnet and that both the rotor and the stator poles have 'teeth'.

The interaction between the teeth of the rotor and those of the stator poles plays an important role in the way this kind of stepper works.

Fig.1 shows the inner working of a two-phase hybrid stepper. It shows an axial view of the inside of the assembled stator and rotor at left, while at right is shown a side view of the rotor alone.

The rotor consists of an axially polarised cylindrical permanent magnet, with toothed 'cups' at either end. Both of these cups have 50 teeth, with the tooth pitch thus corresponding to an angle of rotation of 7.2° (360° ÷ 50).

Importantly, the two cups are offset from each other by one-half of the tooth pitch, so the teeth of one cup are aligned with the gaps between the teeth of the other cup. This gives the motor an effective step resolution of 3.6° degrees (7.2° ÷ 2).

Each of these rotor cups effectively provides that end of the rotor's magnet with 50 "micro pole tips" spread around the cup periphery, each capable of interacting with the teeth of the stator electromagnet poles.

So the rotor magnet effectively has 50 north pole teeth and 50 south pole teeth, each spread equidistantly around the circumference of those cups, but with a fixed 3.6° offset between the two sets of teeth.

And when the rotor is fitted inside the stator, the tips of both sets of magnet pole teeth are close to the teeth of the stator poles.

As shown in Fig.1, the motor has four stator poles spaced 90° apart, arranged in pairs which are opposite each other. The pairs of stator windings 180° apart are connected in series but with opposite polarities, so that when current passes through both, one has a magnetic north pole adjacent to the rotor while the other has a south pole adjacent to the rotor.

These magnetic polarities reverse if the current passes through the windings in the opposite direction, with north becoming south and south becoming north.

Winding configurations

Fig.2 shows the two main stator winding configurations for a common two-phase stepper motor. The "unipolar" configuration is shown at left, with the "bipolar" configuration at right. Note though that these names refer to the requirements of the driving circuitry, not the motor itself, which clearly has more than one pole.

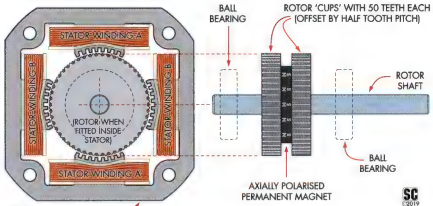


Fig.1: the construction of a typical hybrid synchronous stepper. It has a rotor with an axially polarised permanent magnet and four windings inside the laminated stator. Both the rotor and the stator poles have teeth, this allows the rotor to turn clockwise or anti-clockwise in small increments (typically 3.6°).

In the unipolar arrangement, the two stator windings for each phase are connected in series, with their interconnection point brought out as a centre tap. So there are three wires for each phase, eg, A1-CT-A2 and B1-CT-B2 for a total of six wires. You can recognise motors with this configuration by the number of wires.

With the bipolar configuration, the two stator windings for each phase are either connected in series or in parallel but in either case, only two wires are brought out per phase. So if a stepper only has four wires, it's almost certainly wired in this configuration.

The main difference between the two configurations is the way they are meant to be driven. With the unipolar arrangement, only one side of each centre-tapped pair of windings is meant to be driven at a time, whereas with the bipolar arrangement, both windings must be driven simultaneously.

This makes the bipolar configuration more energy efficient but complicates the required driving circuitry, as detailed below.

Stepping and sequencing

To drive a stepper motor, you need hardware and possibly also software to generate the required sequence of pulses to feed the windings. This process is often called "indexing".

Early on, a basic system of indexing was used, now known as "full-stepping". This allowed a stepper to achieve its innate stepping resolution, for example, steps of 3.6° for a hybrid two-phase stepper with 50-tooth rotor cups, giving 100 steps per revolution.

But after a while, designers found that they could achieve double this stepping resolution by using a more complex indexing system, known as "half-stepping". With the type of stepper mentioned above, you get steps of 1.8°, ie, 200 steps per revolution.

Later designers developed an even more complex indexing system which involved driving the stator windings not with rectangular pulses, but with stepped approximations of sine and cosine waveforms. This system became known as "microstepping" and it allows a stepper to achieve even smaller steps.

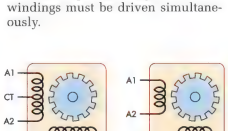


Fig.2: the four stator windings can be connected in two configurations: 1. Opposing pairs of windings connected in series with the centre taps (junctions) brought out, resulting in six control wires (unipolar). 2. Opposing pairs of windings connected in series/parallel without any centre taps, resulting in four wires (bipolar).

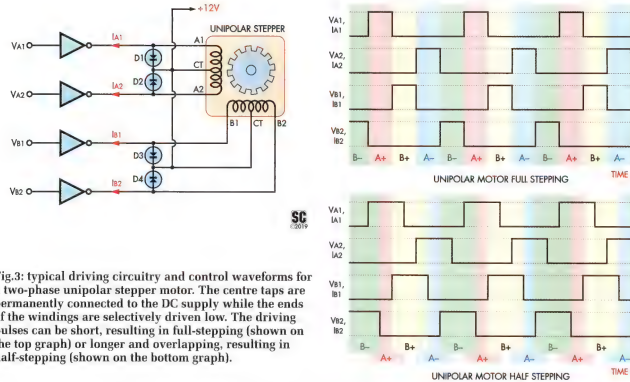


Fig.3: typical driving circuitry and control waveforms for a two-phase unipolar stepper motor. The centre taps are permanently connected to the DC supply while the ends of the windings are selectively driven low. The driving pulses can be short, resulting in full-stepping (shown on the top graph) or longer and overlapping, resulting in half-stepping (shown on the bottom graph).

For example, microstepping a hybrid two-phase stepper with 50-tooth rotor cups can achieve a stepping resolution of 0.9° or 400 steps per revolution.

Another advantage of microstepping is that when the motor is used for multi-step operation (like continuous rotation), its shaft rotation is significantly smoother. But since the hardware and/or software requirements to achieve microstepping are somewhat more complicated than full-step and half-step indexing, we're not going to discuss it in further depth here.

Instead, we are going to look at what is needed for basic full- and half-stepping of unipolar and bipolar hybrid stepping motors.

If you're interested in microstepping, we suggest that you buy a stepper motor driver IC or module with microstepping capabilities and check its data sheet or manual for information on its capabilities and control interface.

Driving a unipolar stepper

Fig.3 shows the basic circuit used for driving a unipolar hybrid stepper motor. The centre taps of the two pairs of windings are both connected to a source of DC power; typically +12V.

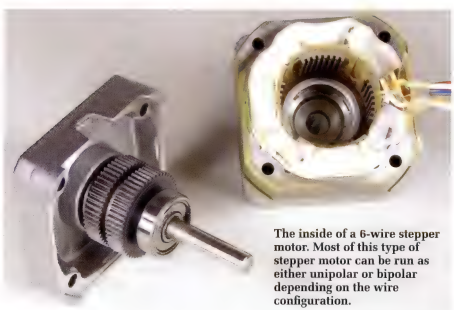
The ends of all four windings are each connected to the outputs of four power inverter gates. Each winding can be fed with a pulse of current by driving the input of its inverter high.

Diodes D1-D4 protect the outputs of the inverters from being damaged by the inductive back-EMF spike from the motor windings when the current flow stops. They ensure that the voltages at A1, A2, B1 and B2 can never rise above +12V by more than a diode forward voltage drop (around 0.7V).

This circuit can drive the stepper in either full- or half-step mode. The only difference is the sequence of pulses fed to the inputs of the four inverters. This is shown on the right of Fig.3. The upper diagram shows the drive sequencing for full-stepping, while the lower one shows the modified sequencing for half-stepping.

For full-stepping, current is only flowing in a single stator winding at any time. The windings are driven in the following sequence: A1, B1, A2, B2, then back to A1. Each pulse results in the motor rotating by a single step. Reversing the sequence causes the motor rotation to reverse.

The steps are colour coded in Fig.3, with steps shown in red, yellow, blue and green respectively. The shows the motor performing twelve full steps,



The inside of a 6-wire stepper motor. Most of this type of stepper motor can be run as either unipolar or bipolar depending on the wire configuration.

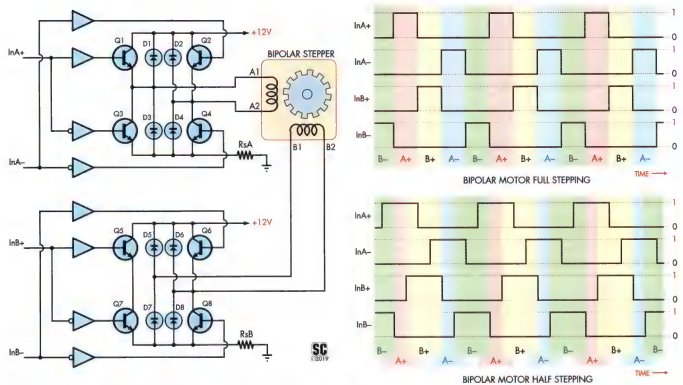


Fig.4: the driving circuitry for a bipolar stepper motor is more complicated, as the windings need to be driven with H-bridges so that current through each winding can be reversed. Its control pulses are identical to a unipolar stepper (Fig.3), with the interface circuitry performing the necessary translation to switch on each transistor when appropriate.

by repeating the full sequence three times.

The modified pulse sequence for half-stepping uses the same basic A1-B1-A2-B2 sequence but with an important difference: now, two adjacent pulses can overlap, and do so for 2/3 of the time, at both the start and finish of the primary pulse in each winding.

So the full pulse sequence for a half-step has become ($B^- + A^+$) | A^+ | ($A^+ + B^+$) | B^+ | ($B^+ + A^-$) | A^- | ($A^- + B^-$) | B^-.

This is made clear by the overlapping colours in the diagram. It is this pulse overlapping which results in the motor performing half-stepping, by providing rotor positions between the single-winding current situations.

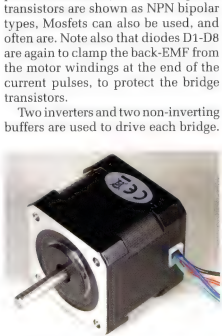
As before, the half-step pulse sequence is simply reversed to get the motor to perform half-steps in the opposite direction. Note that the current pulse waveforms in each winding are now 3/8 on and 5/8 off, whereas the waveforms for full stepping are 1/4 on and 3/4 off.

Driving a bipolar motor

Fig.4 shows the driver circuitry and pulse sequences for full- and half-stepping of a bipolar stepper motor. The main difference in the driving circuitry is we now need a pair of H-bridge driver circuits, to allow us to reverse the voltage and therefore current polarity in either stator winding.

The H-bridge driver for the A1/A2 winding comprises transistors Q1-Q4, while that for the B1/B2 winding comprises transistors Q5-Q8. Although the transistors are shown as NPN bipolar types, Mosfets can also be used, and often are. Note also that diodes D1-D8 are again to clamp the back-EMF from the motor windings at the end of the current pulses, to protect the bridge transistors.

Two inverters and two non-inverting buffers are used to drive each bridge.



A NEMA 17 bipolar stepper motor. This smaller size of stepper motor is used in animatronics, printers etc.

For example, the InA^+ control input drives upper transistor Q1 via a non-inverting buffer, while also driving lower transistor Q3 via an inverter, so Q3 is off whenever Q1 is on and vice versa.

Notice that both Q3 and Q4 will be turned on when neither input InA^+ and InA- is pulsed high. This provides a measure of braking between pulses.

The net result is that when a positive logic pulse is applied to input InA^+, this causes a pulse of current to flow through the upper stator winding in the direction from A1 to A2 and when a positive logic pulse is applied to input InA^-, a current pulse will flow through the same winding in the opposite direction (A2 to A1). The lower bridge operates in the same way.

Resistors Rs_A and Rs_B, between the bottom of each H-bridge and ground, allow the current flowing in each winding to be monitored. This can be used to limit the current and hence protect the motor windings in the event of an overload.

The two graphs on the right-hand side of Fig.4 should look rather familiar. They are in fact identical to those on the right of Fig.3. Which is not all that surprising, since bipolar steppers differ from the unipolar variety only

in the sense that they use a different method to achieve the same result.

So while bipolar steppers need a more complex driver system, they are the same when it comes to the control pulses required for full- and half-stepping.

Microstepping

As mentioned earlier, half-stepping works by overlapping the drive between subsequent windings in the stepper motor. You may be able to imagine how, if you could vary the current level, you could gradually reduce the current in one winding while gradually increasing the current in the next winding, to achieve a smooth transition.

This is effectively how microstepping works. As we said above, we won't go into detail about that method here, except to say that for efficiency reasons, it isn't usually done by linear circuitry. Instead, high-frequency PWM control signals are used, with the duty cycle for each winding drive input varying in a sinusoidal manner, to achieve that smooth hand-over from one winding to the other.

Besides providing a method for even more accurate control over the rotor shaft position, microstepping also provides much smoother rotation, getting rid of the noticeable steps that occur when the motor is driven in full-stepping or half-stepping mode, and most of the ensuing vibration and noise.

Stepper motor sizes

Table.1 shows the dimensions of the most common sizes of stepper motor, according to the US National Electrical Manufacturers Association (NEMA). There are seven standard sizes, ranging from NEMA 8 to the NEMA 42.

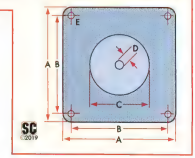
The inside of a 4-phase, 8-wire unipolar stepper motor.

TABLE 1: NEMA STANDARD SIZES FOR STEPPER MOTORS

SIZE	NEMA 8	NEMA 11	NEMA 14	NEMA 17	NEMA 23	NEMA 34	NEMA 42
Faceplate height/width (A)	0.8" (20.3mm)	1.1" (28mm)	1.4" (35.56mm)	1.7" (43.2mm)	2.3" (58.4mm)	3.4" (86.36mm)	4.2" (106.68mm)
Bolt hole spacing (B)	0.63" (16mm)	0.905" (23mm)	1.024" (26mm)	1.22" (31mm)	1.854" (47.14mm)	2.744" (69.7mm)	3.5" (88.9mm)
Pilot flange diameter (C)	0.59" (15mm)	0.866" (22mm)	0.866" (22mm)	0.866" (22mm)	1.500" (38.1mm)	2.875" (73mm)	2.186" (55.52mm)
Shaft diameter (D)	0.157" (4.0mm)	0.197" (5.0mm)	0.197" (5.0mm)	0.197" (5.0mm)	0.25" (6.35mm)	0.375" (9.5mm)	0.625" (15.9mm)
Mounting bolt hole size (E)	0.118" (3.0mm*)	0.157" (4.0mm*)	0.157" (4.0mm*)	4–40 UNC*	0.195" (5.0mm*)	0.218" (5.5mm*)	0.281" (7.13mm)

* Indicates that holes are tapped

Table 1: standard dimensions for the seven NEMA sizes of stepper motors.



The numbers 8, 11, 14 and so on correspond to the dimensions of the motor's square mounting faceplate in tenths of an inch. So the faceplate of a NEMA 14 stepper measures 1.4-inch x 1.4-inch, or 35.56 x 35.56mm.

But there are many stepper motors around which do not correspond to any of these standard NEMA sizes. Some have intermediate mounting plate sizes, others have circular two-hole mounting plates and so on.

Often, steppers salvaged from old printers or disc drives are like this, but they can still be put to use. You can see a selection of steppers in our lead photo, all of different shapes and sizes. Only the one at upper left is a standard size (NEMA 17).

Closing comments

Hopefully, this article has given you a useful insight into the most common types of stepper motor and how they are used. But we should mention another couple of details before closing.

In Figs.3 & 4, we have simply shown the pulse sequences needed to achieve full- and half-stepping but we have not explained how the pulse sequences are generated.

It's easy to generate the required pulse sequences using a microcontroller and that is generally how it's done nowadays. But dedicated indexing/controller ICs can also generate the pulse sequences. These devices only need to be instructed which stepping mode is to be used (full/half/micro), the stepping direction and either the number of steps or the stepping speed and they do the rest.

The common STMicro L297 stepper motor controller IC is one such device, handling not only all the indexing but also the output bridge current sensing and control. It's designed to work together with the L298 dual H-bridge driver IC.

Some stepper motor driver ICs also include an on-chip indexing controller of their own. The Texas Instruments DRV8825 is one such device. It includes an indexing controller to drive its two internal H-bridges. The Toshiba TB6612FNG is similar, with two separate controllers, one for each H-bridge.

We should also mention that unipolar motors can be used with bipolar driver circuits, simply by ignoring the centre-tap of each winding pair and only connecting their ends.

This effectively converts them into a bipolar motor but it will need a higher supply voltage to achieve the same torque compared to driving it in unipolar mode.

Next month, there will be an El Cheapo Modules article which describes three different stepper motor drivers.

Useful links

Stepper motor switching sequence:
www.ni.com/white-paper/14876/en
Hybrid stepper motors:
siliconchip.com.au/link/aam6
Stepper motor basics:
siliconchip.com.au/link/aam7
wikipedia.org/wiki/Stepper_motor
www.cs.uiowa.edu/~jones/step/
Stepper motor sizes:
siliconchip.com.au/link/aam8
NEMA standard:
siliconchip.com.au/link/aam9
reprap.org/wiki/NEMA_Motor SC

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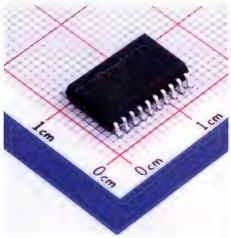


ATtiny816 Breakout and Development Board with Capacitive Touch

Now that Microchip has purchased their arch-rivals Atmel, good things are happening. They are starting to produce microcontrollers with some of the best features that we've come to expect from both companies. One such chip is the ATtiny816 and we're going to describe its features and show you how to use them.

by Tim Blythman

We're fans of both the PIC and AVR families of microcontrollers for different reasons. So it's exciting to see the two worlds come together now that the companies have merged.

The new products are starting to combine the best features of the two families and the ATtiny816 is the one that we've chosen to use first. See the table below for a summary.

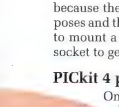
One of the (few) drawbacks of this chip is that, like so many ICs these days, it's only available in surface-mounting packages. But the 20-pin SOIC chip is not difficult to solder; however, you need some sort of "break-out" board to experiment with it.

Silicon Chip Breakout Board

So we designed one! This board not only serves this purpose but also contains some extra components to let you take advantage of its inbuilt capacitive touch sensing. Basically, you get four pushbuttons and/or a slider control essentially for free – there are no components to install. The PCB itself provides these controls!

We've also made provision on the board for five LEDs, because they're useful for debugging and indication purposes and they also look nice. Plus we've provided a space to mount a CP2102-based USB/serial adaptor and a USB socket to get power to the chip.

PICkit 4 programming



One of the thing that stops many people who are already into PICs from using AVRs is the need for a separate programmer. But now that Microchip and Atmel are one, they are starting to release AVR parts which can be programmed with the PICkit 4, and this is one of them. So if you already have the latest PICkit, you won't need any extra development tools.

By the way, we published a review of the PICkit 4 in the September 2018 issue – see siliconchip.com.au/Article/11237 And you can use the same MPLAB X software that's used to develop code for PICs, too, as long as you have the latest version (but note that this support is "beta" so it may be buggy).

As well as showing you how to build and hook up the development board, this article will provide in-depth information on how to program it, including some sample software that will give you a good starting point.

The ATtiny816

We read about the new ATtiny1607 chip in a Microchip advertisement in our November issue. We looked at its specifications and they seemed great but unfortunately, it is only available in a 24-pin VQFN package, which would

ATtiny816 features

Number of pins	20
SRAM	512 bytes
Flash memory	8kB
EEPROM	128 bytes
Maximum clock freq.	20MHz
ADC channels	12 x 10-bit
Event System channels	6
General Purpose I/O pins	18 (17 with UPDI enabled)
Timers	4
Communications	USART, SPI, TWI
DAC	1 x 8-bit

be too challenging for many readers.

That's just the way things are going these days. But we decided to see if they had released any other, similar chips in larger packages.

After extensive searching, we discovered that the ATtiny816 has many of the same new features and is available in a 20-pin SOIC package. If you compare it to the ubiquitous ATmega328P used in the Arduino Uno, the ATtiny816 is really not that "tiny".

It is at the lower end of the product range in terms of RAM and flash space but overall, its hardware features are a big step up from the ATmega328.

The biggest change is the programming interface. The ATtiny816 is now programmed using the single-wire UPDI protocol, rather than the familiar four-wire SPI-compatible ICSP interface used on earlier ATmega and ATtiny chips. This is an evolution of the debugWire debugging interface.

You can see a sample UPDI waveform in Scope.1. It uses a half-duplex asynchronous serial protocol. Since this programming signal is fed to the device's reset pin, that maximises the number of available I/O pins for general purpose use.

Despite using a single pin, this programming scheme is fast compared to the old ICSP system. Admittedly, the ATtiny816 only has 8kB of flash, but the delay between pressing the "Program" button and seeing the results is just a few seconds.

We'll now run through some of the outstanding features of this chip, especially those that jumped out as being bigger than we expected for such a "tiny" chip! For more detailed information, refer to the device's data sheet at: **http://ww1.microchip.com/downloads/en/DeviceDoc/40001913A.pdf**

You may want to refer to the panel "PIC vs AVR" at this stage, to get an idea of why we're excited about the meeting of the two worlds.

Scope.1: the UPDI one-wire program-ming signal used for this new generation of AVR chips. It appears to support reasonably fast re-programming of the chip. These new chips no longer support the old SPI-based in-circuit programming system used in older AVRs like the ATmega328P used in the Arduino Uno. That frees up more pins for general purpose use.

Analog inputs

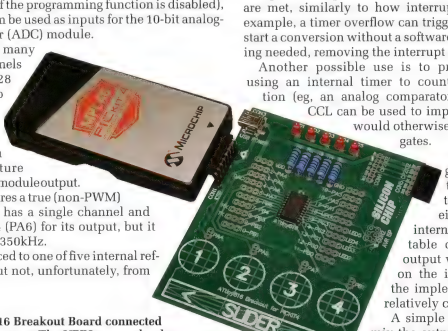
The 20-pin ATtiny816 has two power pins and seventeen I/O pins (eighteen if the programming function is disabled), of which twelve can be used as inputs for the 10-bit analog-to-digital converter (ADC) module.

That's twice as many possible ADC channels as the ATmega328 on an Arduino Uno board!

The ADC can also be used to sample the output of an internal temperature sensor and the DAC module output.

The chip also features a true (non-PWM) 8-bit DAC. It only has a single channel and can only use pin 4 (PA6) for its output, but it can be updated at 350kHz.

It can be referenced to one of five internal reference voltages, but not, unfortunately, from the 5V rail. The highest reference voltage available is 4.34V. It also has an analog comparator which can have its inputs connected to various I/O pins or the output of the internal DAC.



Here's the ATtiny816 Breakout Board connected to a PICkit4 programmer. The UPDI protocol only uses three pins, but we've included a header for all eight pins to ensure that it is connected correctly.

Event System and Configurable Custom Logic

The Event System and Configurable Custom Logic (CCL) are designed to reduce the software and hardware overhead of designs using the ATtiny816.

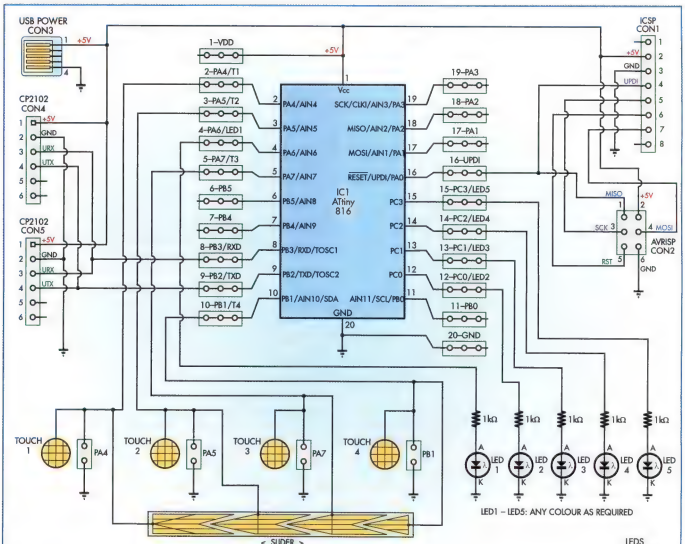
The Event System runs independently of the core once set up, and is capable of triggering events when conditions are met, similarly to how interrupts are triggered. For example, a timer overflow can trigger the ADC module to start a conversion without a software interrupt handler being needed, removing the interrupt overhead and latency.

Another possible use is to provide gated timing, using an internal timer to count how long a condition (eg, an analog comparator comparison) exists.

CCL can be used to implement functions that would otherwise require external logic gates.

CCL involves two programmable look-up tables, each of which takes three inputs from either external pins or internal peripherals. A truth table determines what the output value should be based on the input states, allowing the implementation of basic or relatively complex logic.

A simple use case would be to mix the output from two timers to create a pulse modulated tone. There



ATtiny816 BREAKOUT BOARD FOR PICKIT 4

Fig.1: each pin of the chip is connected to a 3-pin header to make off-board connections easy. A programming header (CON1) is provided, along with a USB power input (CON3) and headers for a USB/serial adaptor (CON4/CON5). Five LEDs are also included for debugging and feedback, plus the four capacitive buttons and slider.

is an Application Note describing the CCL and Event System that you can download at: http://ww1.microchip.com/downloads/en/AppNotes/DS00002451B.pdf

Communications

The ATtiny816 features a USART module, SPI module and TWI module. TWI stands for "two-wire interface", and is a term often used to describe a bus compatible with I²C and SMBus.

As well as a standard serial mode, the USART module also supports SPI master mode and RS-485 mode, and the SPI module supports master and slave modes. All three of the above modules have alternative pin mappings selectable in software, which allows the three modules to operate concurrently without interfering with each other.

Timers

The chip has three independent timer/counter modules as well as a 16-bit real-time clock (RTC) module. The RTC is suited for timekeeping tasks such as providing an application clock or generating periodic interrupts, and can be clocked from an internal low-power oscillator or an external watch crystal (for improved accuracy).

This frees up the other timer/counters for duties such as input capture, waveform generation, PWM and motor control.

The 12-bit Timer/Counter Type D (TCD) is specifically designed for motor control, being able to provide programmable dead time and respond to events from the Event System. That would be useful to react to faults (either from a digital input or the analog comparator), shutting down the motor control output under fault conditions without the delay of an interrupt service routine. 16-bit Timer/Counter A is suited for waveform generation and has three output compare channels.

It can be split into two 8-bit timer/counters, each with

three output compare channels, giving the possibility of up to six waveforms being generated simultaneously. Timer/Counter B is also a 16-bit unit, and is more suited for input capture type operations such as frequency and pulse width measurement. Its input is fed from the Event System, allowing both internal and external events to be measured.

Both Timer/Counter A and B have selectable alternative output pins.

Other features

An internal voltage reference provides 0.55V, 1.1V, 1.5V, 2.5V and 4.34V references for use by the ADC, DAC and analog comparator. These are independent of the actual supply voltage. The 4.34V reference would only be usable with a 4.5-5.5V supply. The ADC can also use VDD as its reference.

A CRC flash memory scan can be set to run and detect any errors which may occur over time in the flash memory. A non-maskable interrupt is generated if a CRC error is detected.

Peripheral Touch Controller

Details on this module in the data sheet are fairly scant. The data sheet states that "the user must use the Atmel Start QTouch Configurator to configure and link the QTouch Library firmware with the application software."

According to comments in online forums, the QTouch Library firmware can use up to 7kB of the ATtiny816's 8kB of flash, and this is backed up by the fact that, according to the datasheet, the PTC is only available on the 8kB ATtiny816 and not the 4kB ATtiny416.

That seems a bit excessive, and we didn't like the idea of using the library code without fully understanding it. So, we went down a different path, and have written our own code to provide a basic touch interface using a similar technique. (See the Sidebar for more information about how the "Shared Capacitance Touch Sensing" works, and how we implemented it).

We can't claim that our software has the sensitivity or features of the QTouch Library firmware. For example, the QTouch Library can calibrate itself, and even detect when the touch sensors may be affected by moisture. Our system can't do that. But it seems to work well despite this, and uses a much smaller proportion of the flash memory.

Microchip has made an excellent guide to the design of capacitive touch PCB buttons, wheels and sliders available at: **http://ww1.microchip.com/downloads/en/appnotes/doc10752.pdf**

We found some great ideas for what sort of touch sensors can be created from nothing more than PCB traces in that document.

The development board

The above is by no means a complete list of all of the features of the ATtiny816; just the ones that we thought were most notable.

So that you can try out some of these features and incorporate one of these chips in a "breadboard" type set-up, we have designed a development/break-out board which allows you to program an ATtiny816 with a PICkit 4 and

Parts list – ATtiny816 development board

1 double-sided PCB coded 24110181, 99mm x 77m
1 CP2102 USB/Serial adaptor module (Silicon Chip Online Shop Cat SC3543)
1 8-pin right-angle pin header (CON1)
1 2x3-pin header (CON2, optional)
1 mini type-B SMD USB socket (CON3)
1 6-pin header (CON4) ***OR***
1 6-way female pin socket (CON5)
20 3-way pin headers (may be snapped from two 40-pin headers)
4 2-pin headers (optional; for external touchpads)

Semiconductors
1 ATtiny816 8-bit microcontroller, wide SOIC-20 (IC1)
5 3mm LEDs, various colours (LED1-LED5)

Resistors (all 1/4W or 1/2W 1% or 5%)
5 1kΩ (colour code brown-black-black-brown-brown or brown-black-red-gold)

PIC vs AVR

We should explain the pros and cons of AVR vs PICs, as the ATtiny816 combines many of the advantages of both architectures.

The main advantage that AVRs always had over 8-bit PICs was the use of a high-speed, high-efficiency RISC CPU core. It can process one instruction per clock and most AVRs can run with a clock up to 20MHz. So you could easily execute 20,000,000 instructions per second with a typical AVR chip.

On the other hand, most 8-bit PICs execute one instruction for every four clock cycles. So even though some of them can run with a clock speed up to 48MHz, that equates to the execution of just 12,000,000 instructions per second – barely half that of the AVRs.

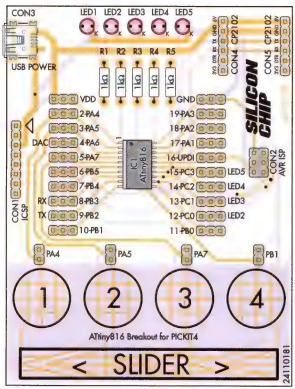
Also, the AVR instruction set lends itself much better to compiler-generated code, so you generally get excellent results using the free avr-gcc "C" compiler, whereas PIC compilers used to cost money (they still do if you want all their features) and usually are far less efficient, generating larger and slower code by comparison.

On the other hand, many PICs contain internal PLLs which allow them to run at maximum speed without an external crystal or resonator. By comparison, AVRs are generally more limited. They mostly lack PLLs, but they usually do have one or more internal resonators. However, these may not allow them to operate at full speed. For that, you generally do need extra external components.

Another advantage of PICs over AVRs is that they are programmed in one pass, with a single HEX file, whereas AVRs have a separate set of EEPROM "fuses" which need to be programmed to access all the device's features. Not only is this a separate step but getting it wrong can effectively "brick" the chip.

And even if you get it right, you may have difficulty reprogramming the chip afterwards, as the programming interface was traditionally clocked based on the crystal and oscillator settings. So there is a bit of a "chicken-and-egg" type problem programming many AVRs.

Finally, PICs were usually cheaper than similarly-specced AVRs and often came with a much more full set of internal hardware peripherals. But that's all changing now that Microchip is starting to add their generous hardware to AVR cores.



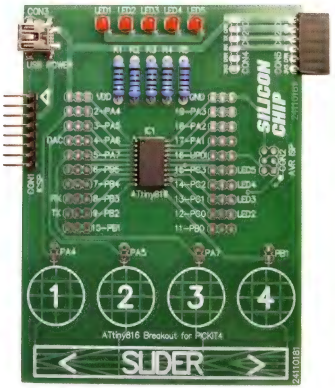


Fig.2: use this overlay diagram and photo of the development board as a guide during construction. You can choose to leave off parts that you don't need. The most interesting feature of this board is the network of tracks at the bottom which provide the same function as four pushbuttons and a slider but with no actual parts needing to be soldered to the board!

connect it up to external circuitry.

The circuit diagram for this board is shown in Fig.1. Each of the 20 pins on the chip (IC1) is broken out to three separate header pins, to make connections to external circuitry easier.

There are five onboard LEDs, LED1-5, in case you need them. These light up when the following outputs go high: PA6 (pin 4), PC0 (pin 12), PC1 (pin 13), PC2 (pin 14) and PC3 (pin 15) respectively.

Programming header CON1 has eight pins, to suit the PICkit 4 (the PICkit 3 only had six, and generally didn't use the sixth). Theoretically, you only need the 5V, GND and UPDI connections to program the chip but the other pins are wired up for completeness.

USB connector CON3 is purely to provide a source of 5V power to run the board (and IC1) – note that the PICkit 4 is not (currently) capable of supplying power to the board while programming a chip in UPDI mode. CON4 and CON5 make it easy to add a USB serial interface, which could be useful for debugging. These connectors are wired up to IC1's default UART pins. If a CP2102 module is fitted, 5V power can come from this instead of CON3.

As described earlier, the PCB incorporates four touch pads and a slider at the bottom. The pads and slider are both connected to the same I/O pins to simplify the code. The pins used to sense the four buttons are PA4 (pin 2), PA5 (pin 3), PA7 (pin 5) and PB1 (pin 10) respectively.

An alternative use

One thing to note is the presence of CON2, which is the old-style six-pin programming header. This is not provided for programming IC1 as this chip does not support such a programming scheme. Rather, it is included so that you can potentially use this board as a way to program older AVR chips using a PICkit 4.

If you need to be able to do that, you can use this PCB and simply fit CON1 and CON2 – nothing else. You can then plug the PICkit 4 into CON1 and connect CON2 to your target device (eg, using a 6-wire IDC ribbon cable). It then simply acts as an adaptor between the two connector pinouts.

Construction

The PCB overlay for the development/breakout board is shown in Fig.2. Use this as a guide during construction.

We recommend that you fit the ATtiny816 IC, IC1, first. Start by applying some solder flux to its pads, then locate the IC with its pin 1 dot towards the top left as per Fig.2. Tack solder one corner pin in place and check that all the other pins line up with their pads.

If not, carefully adjust the IC by re-heating the solder joint and gently nudging it until it is located correctly. Then, tack the pin in the opposite corner and carefully solder each pin.

Inspect the IC using a magnifier and remove any solder bridges using a dab of extra flux paste and some solder wick.

Next, we suggest that you fit USB power socket CON3. Again, start by applying some flux to the pads, including the five small pins and the four large mounting pads. Drop the part in place and move it around until the plastic locating pins drop into the holes on the PCB. Then check that the five small signal pins line up correctly with the pads and tack one of the large mounting pins in place.

Re-check the signal pin alignment, then solder the other

Shared Capacitance Touch Sensing

Touch sensing technology allows simple and intuitive interfaces to be developed. While the touchscreens on our mobile phones are not quite the same thing as what we are demonstrating here, they utilise a similar phenomenon.

The human body has a measurable capacitance, and we can change the intrinsic capacitance of a circuit by coming in contact with it.

It may not even be a direct electrical contact; this effect works even when capacitively coupled across an insulating medium.

Hence the two advantages of the touch sensor. There does not need to be direct contact between the circuit and user, and the actual sensor is nothing more than a means of coupling to the user; in effect, an antenna.

In practice, the sensor is usually a PCB trace, perhaps matched by a second trace to shape and isolate the touch zone. This means the touch sensor has negligible extra manufacturing cost if the design already includes a PCB.

We implemented two different touch sensing algorithms in our demo code. The first was inspired by some Arduino code dating from over ten years ago, which will work with any digital I/O pin. It measures the time constant of an RC network consisting of a pin's internal pull-up resistance and the connected capacitance, including a finger if it is near the pad.

While simple to implement, it is not very sensitive, with variations between the touch and no-touch state only differing by a count of one or two units. We haven't used the code at all in our demonstration, but have left it in the "touch.c" file supplied, for interest's sake.

The second method, which the QTouch Library firmware also uses, is called shared capacitance sensing. From a theoretical point of view, it allows the value of an unknown capacitor to be determined using a known capacitance.

Imagine a capacitor C1, with a known capacitance. We fully discharge this capacitor by shorting both ends to ground. Next, we take an unknown capacitor Cx and charge it up to a known voltage VS by connecting one end to ground and the other to a supply of VS.

Now, we disconnect the capacitors from their respective supplies and connect them in parallel. This shares the charge between them, hence the name of the method.

Once the voltages have settled, we separate the capacitors and measure the voltage across either of them (which will be the same), and call this VF.

Starting with the capacitor charge formula Q=CV, and knowing that

$Q_1 = 0$ **(because V_1=0)**

and

$Q_x = C_x.V_s$

thus:

$Q_{total} = C_x.V_s$

We can solve this to give:

$C_x/C_1 = V_F/(V_S-V_F)$

From this, we can see that the larger C_X is, the larger VF (our measured voltage) will be.

In practice, for touch sensing, the exact value of C_X does not need to be known. We just need to be able to detect a measurable change in its value.

In our ATtiny816, C1 is the ADC module sampling capacitor, which has a value of around 10pF. C_X is the capacitance of the item in contact with the sensor. Typical values for the human body are around 100pF, so we can see that this is at a reasonable level for detecting with our method, keeping in mind that the touch circuitry will add extra capacitance to this amount.

To discharge C1, we can instruct the ADC to take a sample from its internal ground reference. To charge up C_X, we set the analog inpit pin to have its internal pull-up current source switched on (this is actually left on in between samples, so that the circuit is always ready). This brings Cx up to Vs.

C1 will be disconnected from ground after its ADC sample is complete, and we disconnect C_X from its supply by disabling the internal pull-up current. The capacitors are automatically connected together by taking an ADC sample of the pin, and the ADC reading becomes the voltage reading (VF), which we could put into the above formula if we wanted to work out the value of the connected capacitance.

In practice, we take repeated ADC readings, and when we see a rise above a certain threshold, we report that a touch has occurred.

Our prototype circuit gives readings of around 680 ADC counts whilst idle, rising to 900 when a touch occurs. These are equivalent to capacitances of around 20pF rising to around 100pF during a touch event.

The slider uses a similar method, but combines the readings from several adjacent pins. In essence, the closer your finger is to one of the junctions in the slider, the more capacitance is detected at that point.

By performing a linear interpolation between the pin positions in proportion to their measured capacitance, we can calculate the approximate touch location.

three large mounting pins, followed by the five small signal pins, which are partially hidden under the socket body.

We have put slightly enlarged pads on the PCB to simplify soldering them. You should just need to touch the iron (with a bit of solder on the tip) to each pad and it will flow onto the pins.

Only the two outside pads at the back of the USB socket are needed, as this socket is only used for power. The other pins may be soldered for completeness, but you must ensure they are not bridged to any pins, as they may stop the upstream USB socket from working correctly. If you have managed to bridged the pads, again use flux paste and solder wick to remove the bridges.

Fit the resistors next, then the LEDs. Ensure that the cathode flat of each LED goes to the right (adjacent to the "K" mark), and that the longer anode leg is to the left. Solder right-angle programming header CON1 in place next.

You should only fit one of CON4 or CON5. Fit a vertical male header for CON4 if you want to mount a CP2102 module on the board permanently. Fit a vertical female header for CON4 or a right-angle female header for CON5 if you want to be able to plug a CP2102 module into the board.

As noted above, you will probably not fit CON2 to the board. You would only do so if you are building it as a simple programming adaptor. In that case, CON1 and CON2 would normally be the only parts installed (possibly also CON3, if you want to be able to power the target from USB 5V). The 20 3-way male headers are the last essential components to fit. There is one for each pin on IC1.

We find it easiest to solder one pin of each group before the rest; this allows the header to be adjusted if it is not quite vertical, before soldering the remaining pins. You may also choose to leave the header pads vacant if you don't wish to do any prototyping, or you

The challenges of working with a new micro

With any new microcontroller, especially one that's using a new compiler and programmer combination, you're likely to run into a few minor roadblocks. Here's what we found when we first started programming the ATtiny816 using MPLAB X.

For a start, the XC8 compiler has traditionally been for PICs only but they have now added AVR capability (both Microchip's XC8 and Atmel's avr-gcc are based on the GNU gcc compiler).

As a result of this history, the XC8 User Guide is PIC-oriented, and some of the documentation within does not apply to Atmel parts. For example, the syntax it gives for interrupt service routines (ISRs) is PIC-specific. The manual does not explain how to set up an ISR on an AVR part.

Since we are using interrupts to handle the UART's serial receive event, we had to resolve this.

The code we were copying directly from the XC8 User Guide was being rejected by the compiler. Eventually, we found some code that from an Atmel Studio project (the software which was used to program AVRs before Microchip's takeover). This compiled successfully. It has this format:

```
ISR(USART0_RXC_vect){}
```

We ran into similar problems trying to program the AVR's configuration fuses (see the PIC vs AVR panel for an explanation of fuses). The tool for generating the micro's configuration bits creates code in the same style as for a PIC microcontroller, but again, it does not compile.

Like with the ISR, we found some Atmel Studio code that worked instead. It looks like this:

```
FUSES = {
.APPEND = 0,
.BODCFG = ACTIVE_DIS_gc | LVL_BODLEVEL0_gc |
 SAMPFREQ_1kHz_gc | SLEEP_DIS_gc,.BOOTEND = 0,
 .OSCCFG = FREQSEL_20MHZ_gc,
.SYSCFG0 = CRCSRC_NOCRC_gc | RSTPINCFG_UPDI_gc,
.SYSCFG1 = SUT_64MS_gc,
 .WDTCFG = PERIOD_OFF_gc | WINDOW_OFF_gc};
```

In any case, we have commented out this section in our code, so that the programmer will not touch the fuse settings on the chip. The chip's default fuse values are suitable for our project, so leaving them as-is is a lower risk strategy.

We also struggled to find the device I/O header file, which tells the compiler where all the various special registers are located in RAM and provides various handy macros for controlling I/O pins and so on.

Eventually, we found it on our system in this folder: `C:\ProgramFiles(x86)\Microchip\xc8\v2.00\dfp\include\avr\iotn816.h`

We aren't sure what "dfp" stands for.

We also found, while experimenting with the compiler optimisation settings, that the code did not compile at all on optimisation level zero (no optimisation), but did so at level one.

The error message said that the vector table had been truncated, which suggests that the compiled code may not fit in the available flash space, but it only uses 29% of flash space with optimisation enabled, so that seems like a huge difference.

With all the above in mind, we eventually got the code to compile and work. The MPLAB X support for AVRs is still at a beta stage, so we expect many of these problems will disappear over the next few months as support matures.

wish to solder components directly to the pads. The headers marked PA4, PA5, PA7 and PB1 allow you to connect to external touch-pads. These are not necessary if you will be using the onboard touchpads.

We would recommend not fitting them until after you have experimented with the PCB touch pads, as having something extra connected will affect the pads' capacitance and touch sensitivity.

Installing the software

You will need to install Microchip MPLAB X and the XC8 compiler on your system to compile the software and upload it to the chip. These are both free downloads from Microchip. But note that to get the full optimisations from XC8, you may need to pay for a license (not needed for this project.

The MPLAB X IDE (integrated development environment) is cross-platform software that is available for Windows, macOS and Linux, so download the version appropriate for your system from **www.microchip.com/mplab/mplab-x-ide**

It allows you to edit and compile code, and upload the compiled code (HEX file) to the target chip – in this case, the ATtiny816.

The XC8 compiler converts the C code into a HEX file (and optionally also an assembly language file). This is integrated with MPLAB X but you download and install it separately.

When you install the MPLAB X IDE, it will also install drivers for the PICkit 4, if you don't have them already. Ensure the PICkit 4 is plugged into your computer so that MPLAB X can identify it.

By the way, this software can also be used to program PICs and some other Atmel chips.

To use the AVR/PICkit 4 combination, you need to have MPLAB X version 5.05 or newer and XC8 version 2.00 or newer. Compilers, including XC8, can be downloaded from **www.microchip.com/mplab/compilers**

You will also need to download the sample software for this project, available from the SILICON CHIP website. Extract the zip package to a convenient location.

Compiling the demo code

Once both packages are installed, launch the IDE, then use the File>Open Project menu option to locate and load the sample software that you extracted earlier. Next, right-click on the project name which appears in the left-hand pane, and select Properties.

Ensure Conf:[default] is selected, and check that your PICkit 4 is showing and selected under Hardware Tool, and that XC8 (v2.00) is selected under Compiler Toolchain.

If all this is correct, click OK, and connect the ATtiny816 PCB to the PICkit 4 via the 8-way header, ensuring the arrows marking pin 1 line up. You will also need to ensure that the PCB is powered, either from a CP2102 module or via the Mini-B USB socket.

Now click the button labelled "Make and Program Device". This looks like an IC with a green arrow pointing down. The software should compile and then upload the program to the board.

We have also provided a HEX file in the download package, which can be flashed directly to the ATtiny816 using the IPE (integrated programming environment) which is

installed alongside the IDE, in case you are not interested in the code itself and don't want to compile it.

The demo code

The sample software we have written demonstrates some of the exciting capabilities of the ATtiny816 chip. It includes functions to drive I/O pins, use the onboard DAC and ADC, the UART serial port, some basic real-time clock functions and capacitive touch sensing.

The code to do this is contained within the "main" function of the "main.c" file, along with separate "library" files which perform specific functions. We were inspired by the Arduino language to create some similar intuitively named functions for these purposes.

By default, the code continually monitors the touch pads on the PCB. If the pads are touched, then an LED lights up – LED lights for pad 1, LED3 for pad 2 and so on.

The slider (which uses the same I/O pins as the pads) position is also read, and the position is displayed using LED1. It lights at a low intensity with a finger touching the left-hand end and with high intensity at the right-hand end. The granularity that can be achieved can be demonstrated by gradually moving a finger along the slider. This code also demonstrates the use of IC1's internal DAC, which is used to fade LED1 in line with the touched position on the slider; it is not pulse-width modulated.

Note that LEDs2-5 will also light up when the slider is used (and LED1 will change brightness when the pads are touched), since they are sharing the I/O pins on the microcontroller.

Serial debugging data

If you have a CP2102 USB-Serial module connected to CON4, you can also see the raw analog touch values that are being sampled. Open a serial terminal program (eg, the Arduino Serial Monitor, PuTTY or TeraTerm) at 9600 baud, select the appropriate COM port and you will see the data being sent to the terminal.

If you have one of the more recent versions of the Arduino IDE (we are using version 1.8.5), you can also use its Serial Plotter function to show the values as a graph. This can be found under the Tools menu.

The first four numbers printed on each line are the raw ADC readings from each touchpad on a scale from 0 to 1023 (see Fig.3).

You can use this information, along with the formulas from the sidebar about Shared Capacitance Touch Sensing, to estimate the actual capacitance connected to the pin before, during and after a touch has occurred.

The final number is the calculated slider value, which is zero if no touch has occurred and in the range 20 to 80 if a touch is occurring. The values are arbitrary but demonstrate the resolution of the slider pad.

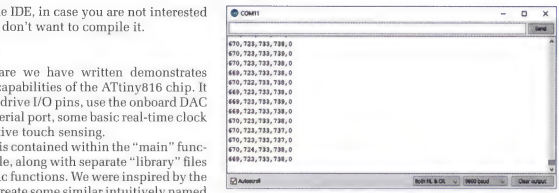


Fig.3: example output of the ADC sample values corresponding to the sensed relative capacitance for each of the four pushbuttons and the slider. You can see that the four first values are fairly steady over time, while the last value is zero. If you bring your finger near or touch a button, one of the values will increase, indicating the added capacitance from your finger.

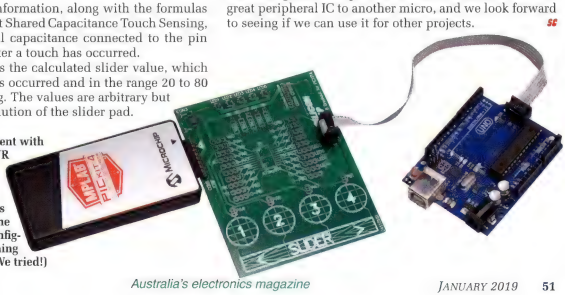
If you find that touches are not being consistently and accurately detected, then the threshold and baseline levels in the program may need to be adjusted. A touch is detected when the raw ADC value rises above the baseline plus threshold value, so this should be set about halfway between the touched and untouched ADC values.

Conclusion

We found the ATtiny816 to be a capable device, and it was easy to work with once we had figured out the quirks of the compiler. But we were a bit disappointed that we could not think of good ways to demonstrate the other features of the microcontroller, such as the CCL or Event System. The 20MHz internal oscillator mode is rated to work down to around 4.5V supply voltage, but we did some quick tests with a 3.3V supply and found most things seemed to work adequately.

But the performance does degrade slightly. For example, the ADC results appeared to drift more than with a 5V supply. Another ATtiny series chip, the ATtiny85, has even had a USB stack ported to it, so if the same can be done for the ATtiny816, then we can expect some interesting projects to appear.

The small amount of RAM and flash memory appears to be limiting, but we expect this microcontroller will make a great peripheral IC to another micro, and we look forward to seeing if we can use it for other projects. SC



If you want to experiment with programming other AVR ICs (such as the ATmega328 on an Arduino board), you can also use our PCB as an ICSP breakout for the PICkit 4. It appears configuration fuse programming is not supported yet. (We tried!)

PRODUCT SHOWCASE

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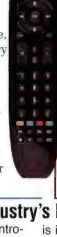

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They've appointed Manny Romero as the new Managing Director.

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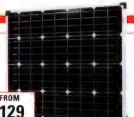

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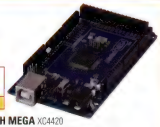


WAS $49.95
$34.95
SAVE $15

DUINOTECH MEGA XC4420

Our most power Arduino -Compatible board. Boasting more IO pins, more memory, more PWM outputs, more analogue inputs and more serial ports

- ATMega2560 Microcontroller

WAS $74.95
$59.95
SAVE $15

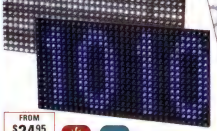
RASPBERRY PI 3B XC9000

Quad-Core 1.2GHz CPU. 1GB RAM. Wireless LAN and Bluetooth® Low Energy (BLE) on board. It can run Raspbian or Ubuntu or even Windows 10 IoT core. Use it as a media player or even use the GPIO ports to connect your Arduino projects.

$49

PCDUINO V3.0 WITH WI-FI XC4350

A high performance mini PC platform that runs on Ubuntu or Android ICS. Features onboard HDMI, USB, SATA, LVDS and Wi-Fi. *Limited stock. In-store only.*

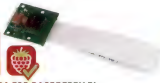


FROM
$24.95
SAVE UP TO $25

DOT MATRIX LED DISPLAYS

Large 32 x 16 pixel LED displays to create message boards, clocks, etc. 10mm LED pitch. Can be daisy-chained for larger displays.

RED XC4621 **WAS $34.95 NOW $24.95 SAVE $10**
WHITE XC4622 **WAS $39.95 NOW $24.95 SAVE $15**
BLUE XC4623 **WAS $49.95 NOW $24.95 SAVE $25**



WAS $24.95
$19.95
SAVE $5

5MP CAMERA FOR RASPBERRY PI
XC9020

Connects directly to your Pi. 2592x1944 resolution. Supports video recording for 1080p @ 30fps, 720p @ 60fps and 640x480p @ 60/90fps.

WAS $19.95
$11.95
SAVE $8

PCDUINO 5MP CAMERA XC4364

Connects directly to your pcDuino V3.0, and captures an active array video and images up to 2592 x 1944.

10% OFF

ALL COMPUTER & GENERAL ELECTRONIC BOOKS

Exclude Magazines & Instructions Booklet

FROM
$49.95
SAVE UP TO $30

TOUCH SCREENS FOR RASPBERRY PI

Compact, portable display to connect directly to your Pi. HDMI input and includes a resistive touch interface.

2.8" 320X240 RESOLUTION XC9022
WAS $59.95 NOW $49.95 SAVE $10
5" 800X480 RESOLUTION XC9024
WAS $99.95 NOW $79.95 SAVE $20
7" 1024X600 RESOLUTION XC9026
WAS $159 NOW $129 SAVE $30

WAS $12.95
$6.95
SAVE $6

LED TRAFFIC LIGHT MODULE XC3720

10mm red, yellow & green LEDs. Inbuilt dropping resistors. Right angle plugs for standing up in breadboard.

25% OFF

WAS $33.95
$24.95
SAVE $9

USB Port Voltage Checker Kit KC5522

REFER: SILICON CHIP MAGAZINE JULY 2013

An easy way to test a USB port to see if it is dead, faulty or incorrectly wired to help prevent damaging a valuable USB device you plan to connect. Voltage is indicated using three LEDs. Kit supplied with double sided, soldermasked and screen-printed PCB with SMDs pre-soldered, clear heatshrink, USB connectors and components for USB 2.0 & USB 3.0. PCB: 44 x 17mm.

WAS $29.95
$19.95
SAVE $10

LED PACK 100-PIECES ZD1694

Contains 3mm and 5mm LEDs of mixed colours. Even includes 10 x 5mm mounting hardware FREE!

- Red, green, yellow, orange LEDs

See website for full contents.

WAS $34.95
$24.95
SAVE $10

LIGHT DUTY HOOK-UP WIRE PACK
WH3009

Quality 13 × 0.12mm tinned hook-up wire on plastic spools. 8 rolls of different colour included.

- 25m on each roll

WAS $27.95
$17.95
SAVE $10

PCB ETCHING KIT HG9990

Complete with assortment of double-sided copper boards, etchant, working bath and tweezers.

WAS $29.95
$24.95
SAVE $5

DEOXIT CONTACT CLEANER & REJUVENATOR - SOLUTION KIT NS1436

This product will not only clean, but it will drastically improve equipment performance.

WAS $35
$25
SAVE $10

PRESS N PEEL PCB FILM HG9980

Includes 5 sheets of 215 x 280mm transfer film in each pack. Full instructions supplied.

WAS $43.95
$29.95
SAVE $14

BREADBOARD - 1660 TIE POINTS PB8816

400 distribution holes / 1280 terminal holes. Mounted on a metal plate. 3 banana terminals. Rubber feet. 157(W) x 237(H)mm.

STEP-BY-STEP INSTRUCTIONS AT:
jaycar.com.au/arduino-uv-meter

MAKE YOUR OWN

UV Meter

PROTECT YOUR SKIN FROM THE SUN'S RADIATION

This simple yet effective project will provide a way to monitor the UV levels in your area, which is helpful to determine what level of sun protection is needed on a particular day. Readings can be listed on the 7 segment display and are stored on the SD card for easy tracking.

SKILL LEVEL: BEGINNER

TOOLS: SOLDERING EQUIPMENT, HOT GLUE OR BLUETACK

WHAT YOU NEED:

DUINOTECH CLASSIC (UNO)	XC4410	**$29.95**
ULTRAVIOLET SENSOR MODULE	XC4518	**$19.95**
DATA LOGGING SHIELD	XC4536	**$10.95**
8 DIGIT 7 SEGMENT DISPLAY MODULE	XC3714	**$9.95**
CAT 5 SOLID NETWORK CABLE	WB2022	**$1.45**
40 PIN HEADER STRIP	HM3212	**95c**

VALUED AT $82.20

NERD PERKS CLUB OFFER
BUY ALL FOR $69
SAVE 15%

SEE OTHER PROJECTS AT:
www.jaycar.com.au/arduino

SAVE UP TO $100
Whilst stock lasts

TEACH YOUR KIDS ELECTRONICS WITH
Littlebits
Easy to use colour coded building blocks with step by step instruction. Ages 8+.

RULE YOUR ROOM KIT KJ9120 **WAS $149 NOW $99 SAVE $50**

GIZMOS & GADGETS KIT KJ9100 **WAS $299 NOW $199 SAVE $100**

KJ9100

FROM **$99**

SAVE UP TO $100

WAS $9.95 **$5.95** SAVE 40%

LED LIGHT SABER WITH SOUND GT3521

Switchable between red & blue. Requires 3 x AAA batteries. 900mm long.

WAS $14.95 **$9.95** SAVE 30%

FM RADIO SNAP-ON PROJECT KIT KJ8978

Bright colourful parts easily snap together. Requires 2 x AA batteries.

SAVE UP TO 40%

WAS $49.95 **$24.95** SAVE $25

14 IN 1 SOLAR ROBOT EDUCATIONAL KIT KJ8966

Can be transformed into 14 different functional robots. Ages 10+.

WAS $24.95 **$19.95** SAVE $5

4 IN 1 TRANSFORMING SOLAR ROBOT KIT KJ8965

It can 'transform' between a T-Rex or Rhino, beetle, Robot and a futuristic miners drilling machine. Ages 8+

Makeblock
Construct Your Dreams

MBOT BLUETOOTH® ROBOT KIT KR9200

Avoid obstacles, follow lines, play soccer, and more. Control from your Smartphone or Tablet, or program using simple drag-and-drop programming blocks or Arduino® IDE. Ages 12+.

WAS $199 **$149** SAVE $50

WAS $59.95 **$49.95** SAVE $10

3-IN-1 ALL TERRAIN ROBOT KJ8918

Use the 6 terrestrial tracks/crawlers to create a working gripper, rover or forklift. Requires 4 x AA batteries. Ages 13+.

WAS $49.95 **$29.95** SAVE $20

AIR POWER ENGINE CAR KIT KJ8967

Operates entirely using air and travels up to 80m on one single tank. No batteries or motor required. Ages 10+.

CAPTURE & REPLICATE
HANDHELD 3D SCANNER TL4250

Scan your desired objects and produce 3D files.

Great for capturing real-world objects and storing them digitally. Compact and lightweight design allows you to move it around the desired target for scanning with ease.

- Connects via USB
- Scan up to 1000(D) x 1000(D) x 2000(H)mm

WAS $399 **$299** SAVE $100

SAVE UP TO $80 ON HDMI UNITS

FROM $59.95 SAVE UP TO $50 — 4K UHD

HDR HDMI SPLITTERS

Split your HDMI source to drive up to four HDMI equipped displays. Transmit up to 18Gbps with no data loss.

2 OUTPUT AC1781
WAS $89.95 NOW $59.95 SAVE $30
4 OUTPUT AC1782
WAS $139 NOW $89 SAVE $50

WAS $129 $69 SAVE $60 — 4K UHD

HDMI MATRIX SWITCHER SPLITTER AC1714

Distribute up to four HDMI sources to 2 displays simultaneously. Up to 4K UHD resolution. Remote control included. 4 x HDMI inputs, 2 x HDMI outputs.

WAS $129 $89 SAVE $40 — 4K UHD

HDR HDMI SWITCHER AC1780

Connect up to 4 HDMI sources to one display (or another receiver). Support up to 4K x 2K resolution. Infrared remote control and mains power adaptor included.

WAS $279 $199 SAVE $80

WIRELESS 1080P HDMI AV SENDER AR1905

2.4GHz wireless transmission up to 15m range. Full HD 1080p HDMI connectivity. Includes infrared emitter, infrared receiver and two mains power adaptors.

SAVE UP TO $100
ON SECURITY CAMERAS

WAS $79.95 $39.95 HALF PRICE

720P WI-FI IP CAMERA QC3835

High quality and easy to set-up. Monitor up to 15 cameras. Record videos to microSD card (available separately). Motion detection. Infrared LEDs for night vision. 2-way audio.

WAS $99.95 $59.95 SAVE $40

720P AHD* CAMERAS WITH IR

Features crystal clear image. IP66 rated. 10m IR range. Supplied with power supply and 18m cable.

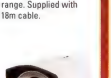
BULLET QC8637
DOME QC8639

WAS $189 $119.95 SAVE $70

1080P AHD* STARLIGHT CAMERAS

Equipped with Sony® Starvis IMX291 starlight sensor. Colour night vision, full colour in low light. IP66 rated.

BULLET QC8678
DOME QC8680



WAS $299 $199 SAVE $100

1080P AHD* PAN-TILT-ZOOM CAMERA QC8676

Supports AHD, TVI, CVI, CVBS (Analogue). IR night vision. IP66 rated.

*AHD - Analogue High Definition

SAVE UP TO 35%
ON I.T. PRODUCTS

FROM $24.95 SAVE UP TO $10

8-PORT NETWORK SWITCHES

Easily create or expand your wired network. Plug and Play. Fanless quiet operation. *Limited stock.*

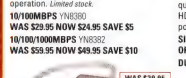
10/100MBPS YN8380
WAS $29.95 NOW $24.95 SAVE $5
10/100/1000MBPS YN8382
WAS $59.95 NOW $49.95 SAVE $10

WAS $49.95 $39.95 SAVE $10

USB 3.0 SATA HDD DOCKING STATIONS

Backup and store gigabytes of data quickly and easily. Suits 2.5"/3.5" SATA HDD (not included). USB 3.0 cable and power supply included.

SINGLE XC4698
ORRP $49.95 NOW $39.95 SAVE $10
DUAL XC4697 **$49**



WAS $39.95 $24.95 SAVE $15

USB 3.0 TYPE C MULTI CARD READER XC4751

Latest USB 3.0 Type C connector for the new generation MacBook® and PC's. Supports SDXC, SDHC, microSD and CompactFlash card slots. Up to 80Mbps transfer rate.

WAS $39.95 $24.95 SAVE $15

SATA TO USB 3.0 ADAPTOR XC4149

A simple way to access files temporarily on a SATA hard drive you no longer have installed. Includes USB 3.0 cable and mains adaptor.

SAVE UP TO $60 ON SPEAKERS

WAS $24.95 $14.95 SAVE $10 — Bluetooth®

WATERPROOF SHOWER SPEAKER XC5630

Comes with suction cup that allows you to stick it to any flat surface. Up to 5hrs playback / 3hrs charge time.

WAS $39.95 $24.95 SAVE $15 — Bluetooth® NFC

SPEAKER WITH NFC TECHNOLOGY XC5209

Microphone and hands free support. 2 x 3WRMS. Up to 7hrs playback/3hrs charge time.

WAS $59.95 $39.95 SAVE $20 — Bluetooth®

RUGGED & WATERPROOF SPEAKER XC5213

2 x 4WRMS. IP66 rated. Impact resistant. Up to 8hrs playback / 2hrs charge time.

Bluetooth® WAS $129 $69 SAVE $60

STEREO VIBRATION SPEAKER XC5229

Massive sound with richer bass and higher overall volume. Rechargeable battery. 2 x 5W (Speaker) / 26W (Resonator). 4hrs of playback / 3hrs charge time.

CLEARANCE

Listed below are a number of discontinued (but still good) items that we can no longer afford to hold stock. Please ring your local store or search our website to check stock. Order online and COLLECT in store. At these prices we won't be able to transfer from store to store. STOCK IS LIMITED. ACT NOW TO AVOID DISSAPOINTMENT. Sorry NO RAINCHECKS.

AV SIGHT & SOUND

		Cat. No	WAS	NOW	SAVE
2 X HDMI TO VGA/COMPONENT & ANALOGUE/DIGITAL AUDIO CONVERTER	HOT	AC1721	$149.00	$99.00	$50
150M 1080P HDMI CAT5/6 EXTENDER WITH INFRARED	HOT	AC1746	$229.00	$159.00	$70
2 X 15 WRMS PORTABLE STEREO AMPLIFIER		AA0904	$79.95	$49.95	$30
2 X 20WRMS STEREO AMPLIFIER	HOT	AA0517	$149.00	$99.00	$50
4K HDMI TO VGA AND STEREO AUDIO CONVERTER		AC1770	$89.95	$49.95	$40
6-WAY SPEAKER SELECTOR WITH INTERNAL PROTECTION		AC1683	$129.00	$89.00	$40
ACTIVE BLUETOOTH® SPEAKER WITH LED LANTERN		XC5228	$24.95	$14.95	$10
AHD TO HDMI CONVERTER	HOT	AC1778	$119.00	$69.00	$50
BLUETOOTH® IN-CAR EARPIECE WITH USB CHARGER		AR3135	$24.95	$14.95	$10
COMPOSITE AUDIO VIDEO TO HDMI 2.0 4K UPSCALER CONVERTER	HOT	AC1776	$149.00	$99.00	$50
DUAL LASER & LED LIGHT SHOW WITH DMX CONTROL	HOT	SL3410	$249.00	$149.00	$100
HDMI CAT6 EXTENDER 4K WITH IR CONTROL	HOT	AC1737	$199.00	$119.00	$80
HDMI REPEATER 4K	HOT	AC1728	$149.00	$99.00	$50
PORTABLE 5.8GHZ WIRELESS 1080P HDMI AV SENDER	HOT	AR1909	$349.00	$229.00	$110

SECURITY

		Cat. No	WAS	NOW	SAVE
1080P AHD BULLET CAMERA WITH IR		QC8685	$129.00	$89.00	$40
1080P AHD VARI-FOCAL DOME CAMERA	HOT	QC8674	$169.00	$99.00	$70
1080P CAR EVENT RECORDER WITH 2.7 LCD DISPLAY*		QV3854	$99.00	$79.00	$20
1080P MINI AHD CAMERA		QC8651	$59.95	$39.95	$20
16 CHANNEL 3MP AHD DVR	HOT	QV3159	$749.00	$499.00	$250
720P AHD PAN TILT BULLET CAMERA WITH IR	HOT	QC8670	$149.00	$89.00	$60
720P AHD WIRELESS RECEIVER & CAMERA KIT	HOT	QC8663	$279.00	$179.00	$100
8 CHANNEL 1080P AHD DVR	HOT	QV3157	$499.00	$349.00	$150
8 CHANNEL 1080P DVR KIT WITH 4 X 1080P CAMERAS	HOT	QV3166	$699.00	$499.00	$200
9 HIGH RESOLUTION AUTO LCD MONITOR WITH HDMI INPUT*	HOT	QM3874	$219.00	$149.00	$70
LCD CLOCK WITH HIDDEN 720P CAMERA	HOT	QC8690	$129.00	$69.00	$60
MOTION ACTIVATED OUTDOOR CAMERA 720P WITH IR FLASH		QC8048	$99.00	$69.00	$10
SPARE WIRELESS CAMERA TO SUIT QM3840/52		QM3854	$105.00	$69.00	$40
WIRELESS DOOR BELL WITH DOOR / WINDOW SENSOR		LA5655	$39.95	$24.95	$15

IT/COMMS

		Cat. No	WAS	NOW	SAVE
3W VHF MARINE RADIO TRANSCEIVER - WATERPROOF		DC1093	$129.00	$69.00	$40
5W UHF CB RADIO WITH MICROPHONE DISPLAY & CONTROL	HOT	DC1122	$249.00	$149.00	$80
5W VHF MARINE RADIO TRANSCEIVER		DC1096	$134.00	$89.00	$45
APPLE IMAC® ARTICULATING DESK MOUNT BRACKET*		CW2870	$39.95	$19.95	$20
GOOSENECK WINDSCREEN/CIGARETTE LIGHTER GPS MOUNT		HS9902	$29.95	$14.95	$15
RACK MOUNT CAT 5 PATCH PANELS		YN8046	$49.95	$34.95	$15
TELEPHONE ISOLATION ON HOLD KIT		YT6070	$29.95	$19.95	$10
TPLINK DECO AC1300 MESH	HOT	YN8444	$399.00	$299.00	$100
USB 2.0 TYPE-C TO DISPLAYPORT CONVERTER		XC4971	$39.95	$24.95	$15
USB 3.1 TYPE-C 2.5" / 3.5" SATA HDD DOCKING STATION		XC4672	$64.95	$34.95	$25
USB FLASH DRIVE WITH LIGHTNING CONNECTOR		XC5628	$59.95	$34.95	$25
USB TYPE-C AV MULTIPORT ADAPTOR		XC4967	$99.95	$69.95	$30
USB TYPE-C TO 3.5MM AUDIO AND MIC CONVERTER		XC4955	$29.95	$19.95	$10
VGA TO COMPOSITE AND S-VIDEO CONVERTER		XC4871	$49.95	$29.95	$20

**Limited stock.*

POWER

		Cat. No	WAS	NOW	SAVE
8 TO 32V DUAL OUTPUT LABORATORY POWER SUPPLY	HOT	MP3087	$399.00	$349.00	$50
0.3 TO 30V, 0 TO 3.75A PORTABLE LABORATORY POWER SUPPLY	HOT	MP3844	$199.00	$139.00	$60
1000 LUMEN CREE LED 10W TORCH		ST3478	$29.95	$17.95	$12
12-24V BATTERY TESTER		QP2263	$24.95	$14.95	$10
12V 10W MONOCRYSTALLINE SOLAR PANEL		ZM9054	$49.95	$34.95	$15
12V 20A DC TO DC CHARGING REGULATOR		MB3684	$89.00	$69.00	$30
12V 20W MONOCRYSTALLINE SOLAR PANEL		ZM9055	$79.95	$49.95	$30
20-AMP 12V SUPER SOLAR PANEL REGULATOR		MP3126	$69.95	$29.95	$20
240VAC ALUMINIUM 4ft LED LIGHT STRIP WITH SWITCH		ST3946	$54.95	$39.95	$15
4-WAY POWERBOARD HUB WITH 15M EXTENSION LEAD		MS4039	$39.95	$24.95	$15
60 MINUTE FAST CHARGER WITH USB PORT		MB3561	$49.95	$29.95	$20
LED PROJECTION LIGHT		SL3403	$69.95	$34.95	$35
PORTABLE RCD WITH 4 X 15A SOCKETS TO 15A MAINS PLUG		MS4047	$99.95	$69.95	$30
RECHAREGEABLE UNDERWATER LED LIGHT - RGB		SL3945	$49.95	$29.95	$20

HARDCORE

		Cat. No	WAS	NOW	SAVE
ARDUINO COMPATIBLE LONG RANGE LORA SHIELD		XC4392	$69.95	$48.95	$21
ARDUINO COMPATIBLE YUN WI-FI SHIELD		XC4388	$69.95	$48.95	$21
CHIBITRONICS LED STICKERS STARTER KIT		KJ9330	$49.95	$19.95	$30
CIRCUIT SCRIBE MAKER KIT		KJ9310	$119.00	$79.00	$40
DRAW CIRCUITS CIRCUIT SCRIBE BASIC KIT	HOT	KJ9340	$69.95	$29.95	$40
ESD SAFE TEMPERATURE CONTROLLED SOLDERING STATION	HOT	TS1440	$299.00	$199.00	$100
GAMEDUINO FOR ARDUINO		XC4550	$49.95	$29.95	$20
LONG RANGE LORA IP GATEWAY	HOT	XC4394	$149.00	$99.00	$50
PRO SOLDERING GAS KIT WITH SCREWDRIVER SET		TS1115	$129.00	$89.00	$40
SOLAR POWER METER	HOT	QM1582	$129.00	$69.00	$60
SQUISHY CIRCUITS DELUXE KIT		KJ9352	$129.00	$89.00	$40
TEMPERATURE/HUMIDITY DATALOGGER		QP6013	$119.00	$79.00	$40
THERMOCOUPLE THERMOMETER - 2 INPUT		QM1601	$94.95	$59.95	$35
USB 3.0 TYPE-C HUB AND CARD READER WITH POWER DELIVERY		XC4308	$79.95	$49.95	$30

GADGETS/OUTDOORS

		Cat. No	WAS	NOW	SAVE
2000-LUMEN 4 BAR LED CAMPING KIT	HOT	SL3989	$169.00	$119.00	$50
600 LUMEN RECHARGEABLE LED SPOTLIGHT		ST3316	$79.95	$49.95	$30
8 PIECE 1000V VDE SET		TD2631	$59.95	$39.95	$20
BIKE AIR HORN - RECHARGEABLE WITH PUMP		GH1113	$34.95	$19.95	$15
BUILD AND FLY CONSTRUCTION BLOCK QUADCOPTER		GT4192	$49.95	$29.95	$20
FOLDING QUADCOPTER 2.4GHZ WITH VIDEO & WIFI		GT4198	$99.00	$79.00	$20
LED CANDLE SET WITH REMOTE CONTROL		ST3960	$24.95	$14.95	$10
NON CONTACT BODY THERMOMETER W/SMARTPHONE APP	HOT	QM7201	$49.95	$24.95	$25
PEN STYLE RF PRESENTER WITH LASER POINTER		XC5410	$24.95	$14.95	$10
PEST REPELLER U/SONIC DUAL TRANSDUCER		YS1628	$59.95	$39.95	$20
PORTABLE 4L 12V COOLER / WARMER	HOT	GH1384	$39.95	$19.95	$20
PORTABLE 7.5L 12V COOLER / WARMER		GH1386	$89.95	$59.95	$30
RECHARGEABLE MINI EVAPORATIVE COOLER FAN	HOT	GH1285	$109.00	$69.00	$40
SKY WALKER ROLL CAGE QUADCOPTER		GT3952	$29.95	$19.95	$10

Workbench Essentials:

There has been an obvious resurgence in people getting back to the workbench and reviving skills involving manual dexterity. As you will see across the following pages, Jaycar has all the DIY tools you'll need to equip your workbench so you can create projects from the power of your brain and your hands.

1. **20MHZ USB OSCILLOSCOPE** QC1929
   - Ultra portable
   - USB interface plug & play
   - Automatic setup
   - Waveforms can be exported as Excel/Word files
   - Spectrum analyser (FFT)
   - Includes 2 probes
2. **180W ULTRASONIC CLEANER WITH TEMPERATURE CONTROL** YH5412
   - 2.5L Capacity
   - Industrial grade transducer
   - Digital display
   - Stainless steel tank
3. **1000A TRUE RMS AC/DC CLAMP METER** QM1634
   - Ultra-high current 1000A AC and DC measurement
   - Cat III, 6000 display count
   - AC/DC Voltage: 750V/1000V
   - AC/DC Current: 1000A/1000A
   - Carry case included
4. **100MHZ DUAL CHANNEL OSCILLOSCOPE** QC1936
   - 7" colour LCD
   - PC connection via USB
   - SD card support
   - Lightweight and compact
   - Includes 2 probes and USB cable
   - Built-in waveform generator
5. **BENCH VICE** TH1766
   - Made from hard-wearing diecast aluminium
   - Vacuum base and ball joint clamp
   - 75mm opening jaw
   - 160mm tall (approx)
6. **0-15V ANALOGUE BENCH VOLTMETER** QP5040
   - 3V and 15V scales via separate banana plugs
   - Zero offset adjustment
   - Quick and easy to read display of volts

UP TO 30% OFF

WAS $59.95 $49.95 SAVE $10

PORTASOL® TECHNIC GAS SOLDERING IRON TS1305

Adjustable tip temperature up to 450°C. 10-60W equivalent electrical power. 60 min (approx) operating time. Flint ignitor in end cap. 170mm long.

WAS $99.95 $69.95 SAVE $30

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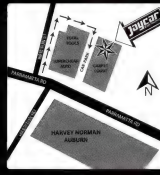

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SERVICEMAN'S LOG

Chasing wild geese isn't as fun as it sounds

Dave Thompson

I don't know about other servicemen, but there always seems to be something in my household that needs fixing. I'm not just talking about stuff I encounter in my day job, or even the computers or phones in the office that get messed up with updates or apps that don't work. I mean those domestic jobs that always crop up that often need a serviceman's touch.

For example, we were experiencing an intermittent problem with some of the devices in our home theatre system.

Now and then, we'd lose power and while the TV still worked, the amplifier and disc player would go dark. All the plugs were fully pushed into a four-socket power board, except the TV, which plugged in further along the wall.

It didn't take long to discover that this power board suffered from the same problems that I've seen readers mention in several letters published in SILICON CHIP; in other words, it was cheap, nasty rubbish. A tap with my foot on one edge of the board resulted in power dropping out. Another tap in a different place restored it.

I couldn't be bothered tearing it apart to find the root cause; I've been down that road before and there is typically nothing fixable inside anyway. What really ailed it was poor design and shoddy manufacturing.

I solved the problems by replacing the power board with a new, better-quality model. While this issue was easy enough to deal with, it still took time and effort to track the fault down.

There was a more trying example recently when we awoke to lukewarm hot water and struggled to get in a couple of showers before the water was too cold. This is unusual as we are on a night-rate power plan; heating our water overnight takes advantage of the much cheaper off-peak electricity rates. While this usually works out well, something appeared to have gone awry.

As usual, my serviceman brain immediately kicked into gear, mentally troubleshooting the possible causes. But there were some "wild card" factors muddying the waters. Around ten months ago, it was announced the drinking water in Christchurch, long prided on being the clearest and cleanest in the world (if local lore is to be believed), was to be chlorinated.

This caused quite the backlash from the masses, including me, who struggled with the reasoning behind it. Due to a gastro outbreak in a city in the North Island – the result of contaminated tap water – our local council got spooked and decided that for the public good, chlorine must be introduced immediately into our water supply.

A TAP WITH MY FOOT ON THE EDGE OF THE BOARD RESULTED IN POWER DROPPING OUT

ANOTHER TAP IN A DIFFERENT PLACE RESTORED IT...

Items Covered This Month

- Cold showers in Christchurch
- BWD 275 dual-range 36/72V power supply repair
- Static from a Codan X2 high-frequency transceiver
- Cordless vacuum repair
- A not so steamy kettle

*Dave Thompson runs PC Anytime in Christchurch, NZ.
Website: www.pcanytime.co.nz
Email: dave@pcanytime.co.nz

What that outbreak had to do with us, a whole island and a half away, baffled me.

I suppose that any of the hundreds of bores that tap vast aquifers deep under Christchurch *might* suffer the same fate as those 'up north', requiring the bore's hardware (some of which dates back almost a hundred years) to be replaced (no doubt at a huge cost to the taxpayer). But adding chlorine to our water just seems like a solution looking for a problem.

To placate the nay-sayers, the council claimed chlorination would only be required for a short period, and only in a few problem areas while all the bore heads were tested and/or upgraded. It all sounds plausible, especially as the quakes might well have had some impact on the state of these aquifers and bores.

But the latest news is that the water could be chlorinated for years, Christchurch-wide, which is just adding to everyone's anxiety over the issue.

Anyway, the point to this backstory is that since this chlorination program started, more than 2000 hot

water tanks in homes around the city have corroded through and been ruined, apparently by the chlorine in the water. This number doesn't take into account the hundreds of plumbing leaks and pipe failures that are also attributed to the chlorination of the water supply.

Now I'm no plumber or water-tank guru, so I can't say for sure if this was a just glitch in the matrix (ie, a coincidence) or merely a problem with some older pipes and cylinders, of which there are likely many still around Christchurch.

Either way, it's an unexpected boon for water heater installers and manufacturers. The rest of us are mostly just concerned about how our own cylinders and pipes will fare in this situation.

The game is afoot

Of course, chlorine-driven corrosion sprang to mind as a possible cause for our lack of water. The first thing I did was to make sure that we didn't have a new indoor swimming pool beneath the hot water tank.

The second thing was to check the breaker at the switch-box to make sure it hadn't tripped. Everything looked OK, so with those two causes ruled out, I'd have to look further afield.

Now before I get flamed by those far more knowledgeable than I am about low-pressure home hot water systems, let me qualify my troubleshooting process with the fact I know next to nothing about how it all works. I realised there could only be a few possible causes of no hot water, the most obvious of which would be the heating element itself failing.

The element in our heater is a resistive immersion type, so its continuity should be easily measurable, and the wiring to, and within, the heater panel should ring out as well. I'd need a multimeter for these tasks; I chose my analog model as it is easier to read in tight corners.

I then did what all servicemen love to do; break out the tools and remove whatever covers I could get off in the hope I'd see something really obvious, such as soot deposits, a broken wire or a blown fuse. Maybe I'd get lucky!

The water heater looked to be relatively new and sits in a cupboard upstairs. I'm guessing it replaced the uninsulated, low-tech, late-fifties original when the house's second storey was added in the mid-nineties and everything was relocated from downstairs to the upper level.

I removed the large, circular "biscuit-tin" lid that shields the wiring and electrics. This is held on with two diametrically-opposite PK style screws, attaching it to a round housing that is spot-welded to the side of the cylinder.

Once the screws were removed, it was relatively easy to pry the cover away with the edge of a screwdriver (you could use your fingernails if they are tough enough!).

As the shaft for the thermostat control protrudes through the cover, the temperature-setting knob must also be removed for the cover to come away completely. In this case, the knob just pulled off the pot shaft with a little outward pressure. Once the cover is off, the wiring to the element and thermostat is very easy to access.

Everything looked perfect, as if it had been installed yesterday, so no obvious fault presented itself here. As I was checking this during the day, theoretically there shouldn't be any power present on any of the terminals, but while I might sometimes be an imbecile, I'm not insane, so I tripped the breaker at the switchboard.

And though there is an isolating switch on the wall of the hot water cupboard, I wasn't about to take it on faith that it was wired correctly either. Instead, I used my mains-detector tool to check for mains-level voltage in the wiring at all the points from the wall-switch to the element.

When the tool started screaming at me, indicating voltage was present, I considered my caution justified.

However, I know from experience that this tool can sometimes be too sensitive. I suspected it was picking up stray emissions from a mains-wiring loom that ran through the floor cavity just beneath the heater cupboard on its way to the main switchboard downstairs. In reality, I couldn't get anywhere in the cupboard without the detector going off.

To be 100% sure whether mains voltage was present, I'd have to measure it, so after removing the two retaining screws for the isolating switch plate and dropping it clear of the wall, I used my multimeter to ring out the system.

I measured zero volts on all points, regardless of the wall switch or thermostat control's position, so I was confident there was no power flowing to the heater and that my detector was indeed picking up stray emissions.

With everything now electrically dead, I removed one of the Active leads from one side of the element and with my meter set to the ohms range, measured the element itself.

This type of element actually has four terminals; I assume that there are two separate-but-identical elements as they were wired in parallel, with each pair of terminals bound to the adjacent pair with heavy brass links.

All I needed to do was put a lead on each bus bar to measure the resistance. I got a reading of around 12Ω. I didn't know what it should be, but that sounded about right.

At least it wasn't open circuit, and as the main breaker hadn't blown, I knew it was unlikely to be shorted out. I also tested the thermostat and it clicked in and out fine, with continuity from the power leads to the elements when it was on.

Since I had reasonable element resistance and all the wiring looked good to and from the switch plate, and with the switch properly isolating the mains feed to the system, nothing appeared untoward here. If there was no power getting this far, there must be something else somewhere upstream preventing it from getting to this point.

Doing a sparky's leg-work

I digress now to another back-story that may have a bearing on this problem; when we renovated this house, we replaced a lot of the ropey old wiring we found in the walls and ceilings with new cables. I did most of this work under the careful scrutiny of a licensed electrician.

He'd just had surgery and couldn't do the monkey work, so I did it all while he sat watching, drinking lots of coffee, all the while telling yarns and talking the usual tradie rubbish. Once I finished each job, he'd hobble over, check and sign off on whatever I'd done.

When the water went cold, I had a sudden thought that I might have messed something up wiring-wise and it had failed. While it wasn't all that likely, given we are now two years down the road from doing all that work, the possibility did cross my mind.

With the fuse and wiring apparently

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~SO I DID THE MONKEY WORK WHILE HE SAT WATCHING, DRINKING COFFEE & TELLING YARNS

OK, there wasn't much left to check on. What I did next was what I usually do when I need to know something; I phoned my friend, Google.

I searched for and found a link to the New Zealand Standards for Storage Water Heaters, but after downloading the file and discovering it was only a preview and that they wanted $61.20 for the actual PDF, I widened my search instead.

Fortunately, I found many installation brochures for heaters similar to ours and most included schematics and wiring diagrams for installers. Just what I needed!

With my newly-acquired knowledge, I looked at the system again. It seemed to me that if no power was getting to the switchboard, and then on to the heater, there could be something wrong with the ripple-control system, part of which is located in the meter box on the side of the house.

In the two years we've lived at this address, this was only the second time I'd opened that box. The meter was changed for a smart meter just as we moved in (and had a wire fall off the pole fuse, as described previously in Serviceman's Log). Since then, nobody has had cause to disturb the contents.

The tone control blues

Sitting next to the meter in the box is the ripple control relay. This heavy-duty contactor controls when the hot water is switched on, based on a signal superimposed on the mains power waveform.

When the signal is received, the relay turns on or off as instructed. Clearly if this was playing up, and failing to switch on at the start of the off-peak period, we'd get no water heating.

The trouble was, I couldn't think of any way to test it other than to check whether there was power to the heater element when there should be power to it – ie, during the off-peak period. But the point of the tone control system is that it can vary from day to day (or more realistically, night to night). Precisely when that should occur on a given evening is anybody's guess.

Ripple control has been used for years in most big cities to prevent the electrical system from being overloaded. If everyone in the neighbourhood turned their water heaters on at the same time, something would blow out at the sub-station.

To avoid this, the ability to heat water tanks on-demand was removed from the consumer and instead, households would be assigned certain times that their cylinder would be switched on and off, all controlled by 'the man' somewhere out on the grid. In practice, this works very well, but it makes things tricky when an amateur like me wants to test the system.

Given that we're on a night-rate plan, I could stay up all night next with a multimeter across the element, waiting for signs of voltage as the ripple-control instructs it to switch on. Or I could poke about the various terminals on the ripple control hardware in the meter-box during the day to see if (maybe) there was power going in, ready to be switched to the cylinder, or not.

However, neither of these options seemed particularly attractive, especially given my reluctance to be electrocuted while playing around with high-voltage hardware, about which I know next to nothing. I closed the meter box and resigned myself to getting my electrician friend to troubleshoot the system for me.

This was bad news in many respects, not the least of which was the fact we'd likely not be showering for at least the next day while we waited for the electrician to get his rear end into gear, so it was with some reluctance that I fired up my computer again to find his number.

Getting to the bottom of it

However, shortly after my machine woke up, an email alert popped up advising me I had a communication from my electricity provider.

When I downloaded and read the email, all became clear. The message was an apology, detailing how they'd been having problems with their network and that some households would not have water heating at the usual times, or at all.

This was good news, as it meant that

all we had to do was wait, and theoretically, it would all just work again – as long as I hadn't messed anything up while stumbling around in the figurative darkness!

The next morning, it was gratifying to feel the hot water back up to temperature. Typical serviceman that I am, I just assumed something had to have failed, or gone catastrophically wrong for the system to have gone down and that I had to get into it to find out why. In the end, all I had to do was nothing. The serviceman's curse strikes again!

BWD Power supply repair

J. C., of Murrumbeena, Vic, loves a challenge. He recently acquired two BWD power supplies for free. That sounds cheap but it was because neither of them worked! Here is how he fixed the BWD model 275 power supply...

The BWD 275 would switch on but did nothing else; the current and voltage controls didn't do anything and the output voltage was zero. I took the covers off and had a look for clues of which there were three: one transistor was missing (and all of the others on the circuit board had been replaced), two of the four screws holding the transformer down were missing and the ammeter pointer had been repaired.

I found two suitable screws and fixed the transformer securely. The missing transistor was a JFET that the circuit diagram said was a "Selected Component". It is used as a constant current diode in the +16V section of the auxiliary supply. I made a replacement +16V supply on a piece of Veroboard with an LM317 voltage regulator, two resistors and a trimpot.

To fit this, I had to remove two other transistors and two resistors from the main board. Turning on the power supply revealed that the +16V rail measured 0V.

Next, I checked the 30VAC output from the transformer to the auxiliary supply. That measured zero too. When I touched one of the wires, it was loose, every strand broken. I stripped it, tinned it and re-attached it and then the power supply started working again.

I don't know why two transformer mounting screws were missing. Maybe it was a botched repair attempt, prompted by the failure of the JFET. There were marks to show that they were originally fitted and without them, the transformer moved a little bit every time the power supply was picked up and put down. This caused the short wires to flex at the circuit board end and eventually break.

Because all of the other transistors had been replaced, including two other "Selected component" JFETs, I had to change one resistor to get the V_{MAX} for the 36 and 72V ranges set correctly. At the same time, I replaced the respective trimpots with 10-turn types.

The ammeter also required a resistor change to allow accurate adjustment of the two ranges. I had forgotten about the repaired ammeter pointer. It broke again when the pointer went full scale very quickly.

I re-glued the broken pointer and changed another resistor and was able to adjust the maximum current ranges such that the pointer won't break itself again (hopefully).

I later noticed that the V_{MAX} settings became intermittent and I suspected that IC1 was the culprit; it contains six transistors arranged as two differential amplifiers. I pulled it out of its socket and cleaned its legs with a glass fibre brush, applied some contact cleaner and re-installed it.

The problem went away. This is why I'm not keen on IC sockets; they tend to become intermittent after a few decades.

I learned a few things during this repair. The three JFETs in the circuit marked as "Selected components" were chosen at manufacturing time based on the V_{GS} (gate-source voltage switch-on threshold). Without knowing what this was and the V_{GS} of the replacement FET, you will have to change some resistor values to get the circuit to work correctly.

Also, before setting the Terminal Switch to "SET I", it's a good idea to connect a 5-10Ω power resistor across the output terminals and set the Terminal Switch to "USE", to verify that the current control does what it's supposed to do. In the "SET I" position, it connects a 0.1Ω resistor across the output and if something is wrong, this makes it easy to blow the fuse or even the output transistors.

Cold weather Codan X2 HF transceiver fault

R. M., of Sydney, NSW, got a bit of a shock as he was driving along when his HF transceiver decided to give him

a blast of static for no particular reason. This very annoying fault would have to be addressed so despite being a relative amateur, he decided to have a go at fixing it...

I'm not what you would call a technician but from a very young age, I've had an interest in electronics. As a licensed amateur radio operator, I have just enough electronics knowledge to do simple repairs to my own equipment. For more complex repairs, I turn to my friend for help, a very experienced technician.

So, when a strange intermittent fault developed in my Codan X2 transceiver, I thought I might have a go at tracking it down. The Codan X2 is a 25-year-old 10-channel commercially made 100W HF transceiver which I use with my amateur radio Automatic Packet Reporting System (APRS). This allows my family and friends to keep track of my movements via the internet when I'm travelling.

I had to make a few minor modifications to the Codan X2 to interface it with a Byonics Tiny Track 3 APRS kit. When on the move, it turns the X2 on, transmits a position information packet, then switches it off again. This is an excellent arrangement as it conserves my vehicle's auxiliary battery, which powers other equipment.

I have been using this arrangement for about two years. Most of the time it works perfectly, however, the X2 always has had one strange fault that caused it to intermittently break the mute and open the speaker at full volume. As is typical of intermittent faults, it would never appear when the X2 was on the bench.

I tried varying the supply voltage, changing the antenna, transmitting, turning it on and off, but they all had no effect. The system would run perfectly for days just sitting on the bench. Months would go by without the fault appearing then suddenly there it was again, the audio at full volume blaring away.

Every week I travel from Sydney to the Southern Highlands of NSW to work on my parents' property. My truck sits outside for a day or two, not being used until my return journey to Sydney. Over time, I noticed that the fault would mainly appear on cold winter mornings when I was leaving the Highlands. At full volume, the noise was so bad that I had to switch the X2 off.

By the time I had travelled 30km and stopped for breakfast, on turning the X2 back on, the fault had cleared itself. This led me to believe that the fault was temperature related.

On the suggestion of my technical friend, I tried placing it in the refrigerator for an hour. But even that didn't activate the fault as, by the time I had it set up on the bench, the unit had warmed up again.

Reading the X2 service manual, I was able to locate the TDA1020 audio IC on the circuit diagram. My friend had suggested that whatever was causing the fault would probably be associated with this IC.

The IC wasn't difficult to find as the audio board is mounted inside the face panel of the unit. It was relatively easy to remove the front panel to expose the board and the unit could be run with access to the IC. So I sprayed the IC with a can of freezer spray to see what would happen.

This produced a low-level hiss from the speaker but it did not cause the aforementioned fault to occur. Methodically spraying components associated with the IC finally reproduced the fault. When I sprayed a 10µF electrolytic bypass capacitor, the mute suddenly opened with the speaker at full volume, which tapered off as it warmed back up again.

The audio IC is riveted to a small block of aluminium that serves as a heatsink, which in turn is riveted to the chassis. Drilling the rivet out and removing the knobs allowed the audio board to be lifted out of the front panel.

Carefully examining the underside of the board revealed nothing unusual except for a bit of corrosion around the pins of the audio IC. I removed the corrosion with a toothbrush and some methylated spirits and lightly re-soldered all the pins.

Using solder wick, I removed and replaced all four of the ageing electrolytic capacitors on the board. After reassembling, I again sprayed the section of the board which had caused the problem to appear last time. All was silent, as it should be.

Cordless vacuum repair

B. P., of Dundathu, Qld, had the unfortunate experience of buying a second-hand vacuum cleaner that worked fine when initially tested but then was found to be faulty when he got it home. Luckily, he isn't afraid of disassembling something right back to its constituent parts and he managed to get it going again...

After visiting our daughter and using her cordless vacuum cleaner, my wife decided that she would like one of her own. She looked on Gumtree and found one locally, which we went and examined.

It seemed to be working OK and we got it for a reasonable price and headed off. When we tested it at home, I noticed several problems with it. For some reason, the three-position switch was now jamming and the brush wasn't turning. This had not happened when we first looked at the unit, so they must have happened on the way home. I decided to dismantle the unit and try to fix it.

I started with the handle, which is attached to the main body by a single screw. The next thing was to dismantle the handle. This was achieved by first pulling off the decorative covering, which revealed several screws, which I then removed.

With the handle now apart, I could see that the rotary switch operated a lever which in turn operated a PCB-mounted three-position slide switch, which was supposed to be held on by two screws.

Somehow, one of the plastic screw holes had disintegrated and the screw had fallen out and jammed the switch. I removed the four broken plastic pieces and the loose screw. Then I screwed the PCB back on with the remaining screw and fortunately, this was enough to hold it securely, so I reassembled the handle, with the switch now working.

However, the brush still did not turn when the switch was set appropriately, so I would have to look further to find why. I started by removing the bottom cover of the cleaner head, where the brush was.

This involved removing seven screws and this would be routine for cleaning the brush. Everything seemed to be in order here, so with the brush still out, I turned the switch to operate the brush motor.

I found that by swivelling the head, I could get the motor to run intermittently, so this indicated a broken wire or loose connection. I then dismantled the cleaning head by removing eight more screws and checked the wires and the motor but they were all OK.

I then unplugged the head from the

unit and I noticed that there had been some arcing on the two connecting pins, indicating a loose connection. I needed to dismantle the main vacuum cleaner body to find out more.

First I un-clipped the decorative front panel and then undid six screws to separate the body into the two halves. I located the clip connectors at the base of the body and tested the fit of the pins, which were very loose.

After bending the clip connectors to ensure that they had a firm grip on the pins, I reassembled the main body and refitted the handle assembly. Then I reassembled the cleaning head and the connector, making sure to turn the connecting pins 90° so that the damaged area was no longer the section that would make contact with the connecting clips.

With the unit now back together again, it worked correctly, just like new.

Smart kettle repair

R. S., of Hoppers Crossing, Vic, makes problem-solving and repairing various electronic items his hobby. His neighbour is aware of this hobby and decided to take advantage of his generosity with his time when the household kettle decided to go on the blink, as follows...

My neighbour Phil and his wife were having trouble with their kettle, a "bells and whistles" type. The base is used to control the final water temperature in five steps, from 70°C to 100°C.

As is typical for this type of kettle, the base has a central metallic post, about 2mm in diameter, with several concentric rings around it. These fit into slots in the base of the jug and supply power to the heating element along with feedback from the built-in temperature sensor.

I noted that none of the pretty blue LEDs in the base were illuminated when power was applied but the GPO seemed to be working correctly. The base was held together using some annoying tri-wing screws but luckily I had a suitable bit in a Dick Smith toolkit, so I managed to get it apart without further drama.

Inside, I found two separate PCBs. One is best described as the power supply and the other, the control board. They are linked together by a five-way flexible flat cable. The power supply has a two-way flexible flat cable going the main jug connector.

The power board was the main suspect, so I removed it and carefully examined it. The circuit is simple; it is the now-familiar capacitor/rectifier/filter/zener type of supply which requires no transformer. The power board also incorporates a 12V DC coil relay to switch 230VAC to the kettle element, plus a 78L05 5V regulator.

Both the 5V and 12V power rails are fed to the control board as well, along with control signals for the buzzer and relay and a feed from the temperature sensor.

I checked the diodes in the bridge rectifier but they seemed OK. However, the zener diode which regulates the 12V supply was surrounded by some charring on the PCB. I carefully applied 230VAC to the board and measured the voltage across the zener diode. It was only about 2V DC; way too low.

So, I disconnected power and desoldered the zener diode from the board. I measured the resistance across it with my DMM and regardless of the way I connected the probes, I got a reading of just a few ohms. So it seems like this component had shorted out, possibly due to overheating, given the charring I noted earlier.

I guess it was better that it went short-circuit rather than open-circuit as otherwise, the 78L05 could have had a much higher-than-expected voltage applied to its input and that could have fried it, and possibly other components too.

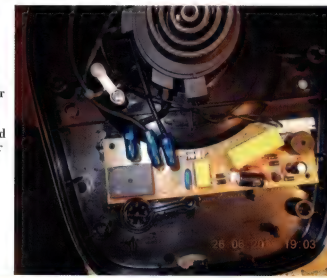
The only 1W zener I had handy was rated at 11V. I figured that was close enough that it should work, so I soldered it to the board and re-applied 230VAC. The 12V rail then came up (to 11V) and I could now measure 5V DC from the output of the 78L05 regulator.

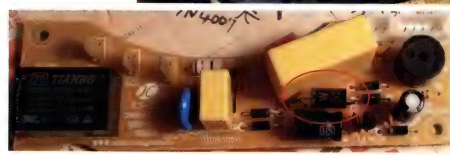
I powered it down, re-connected the control board and once again applied mains power. The pretty blue LEDs began to flash and the buzzer beeped.

That was a good sign, so I decided to pop down to my local Jaycar to get a 12V zener. I figured I would buy a 5W type, seeing as the 1W zener originally installed seemed to have burned out.

The pigtails of the 5W zener are larger in diameter than those of a 1W type; I had to drill out the through-holes to 1.2mm. I mounted it about 7mm proud of the PCB, to allow for better cooling air circulation.

I could then finally re-assemble the entire unit and return it to Phil's wife, Helen. She filled it with water and confirmed that it was back to normal. Now I just need to get Phil to reimburse me the $1.75 that I spent on replacement components! SC





At right is the base of the smart kettle with the yellow power PCB before any changes. Below is the power board after the blown zener diode was replaced (marked ZD1 on the PCB). It was replaced with a 12V 5W zener (circled in red) that had slightly larger leads, so the holes had to be enlarged.

ZERO RISK SERIAL LINK

by Tim Blythman

Want to communicate with and/or program a micro that's connected to mains or a high-voltage supply? Hmmmm . . . r-i-s-k-y – not just to the device, but to you as well! Here's the SAFE way to do it!

Because small computer boards like the Micromite, Arduino and Raspberry Pi are so flexible, chances are you will eventually find yourself using them to control some mains-powered or high voltage battery-powered circuitry.

But there's always the risk that those higher voltages could find their way back to your computer, doing untold damage – and in the worst case, it could be YOU that suffers the untold damage!

This nifty little project allows you to send serial data over an optically isolated link, entirely preventing the dreaded 230V-in-the-USB-socket syndrome.

It can be used for programming the project you are working on, or for monitoring and feedback from a finished project to your computer.

Either way, it provides total isolation. It can also translate 5V serial signals to 3.3V and vice versa. You can even use it to pass data between the USB ports on two separate computers without having to make an electrical connection between the two, avoiding the possibility of Earth loops or other similar problems.

You may have seen our USB Port Protector project in the May 2018 issue (siliconchip.com.au/Article/11065). If so, you'll understand our motivation for this project (sob!).

But this provides even better protection for your PC. It doesn't try to shunt excessive voltages and currents – it won't even let them near your computer!

We've had laptop USB ports fail while plugged into certain Arduino work-in-progress projects which involved mains and battery power.

We aren't exactly sure how it happened, but it appears that some voltages got to certain pins that they were not supposed to.

We wish we'd had this Isolated Serial Link then; it's an expensive lesson to learn!

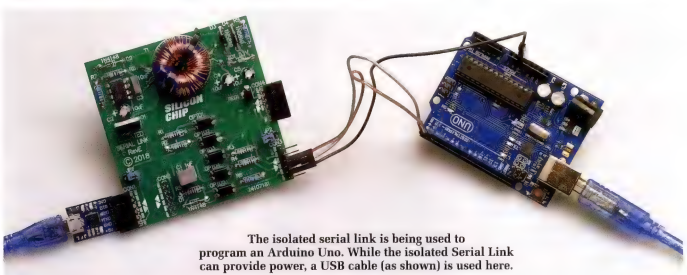
Projects that feature high voltages and high currents always have the potential for damage to delicate components like microcontrollers and even computers. Where possible, it is best to separate the two.

This circuit is simple, easy to build and does just that.

It's also useful for situations even where there are no USB ports involved, eg, to allow two microcontrollers to communicate via a serial link, even if they are running from different supplies which may not share a common ground.

What does it do, exactly?

The Isolated Serial Link provides two optoisolated data lines suitable for full-duplex serial data (ie, simultaneous



The isolated serial link is being used to program an Arduino Uno. While the isolated Serial Link can provide power, a USB cable (as shown) is used here.

sending and receiving). Typically, these connect to the TX and RX pins of a microcontroller or USB/serial converter, although they could be used to pass just about any logic-level signal with a switching frequency up to a bit over 100kHz.

There is also a third isolated data line which can be used to get an Arduino (or similar) board to go into programming mode, so that new firmware data can be sent over the isolated serial link. The board includes circuitry to automatically generate a reset pulse on the target board when required.

The board also has an optional small isolated power supply, capable of providing up to about 100mA at 5V. This circuit is based around a 555 timer IC driving a Mosfet, which in turn drives an isolating transformer. This supply can power some (but not all) Arduino boards without the need for a separate power supply. 5V and 3.3V isolated outputs are provided, to suit various situations.

Alternatively, you can omit the 555 IC and transformer (and associated components) and instead mount a pre-built 5V isolated DC-DC converter module capable of delivering up to 200mA (at 5V and/or 3.3V).

While this module can provide more current, it is a specialised part (compared to the generic parts used in the transformer-based power supply) and its pins are quite close together, so despite its 1kV isolation rating, it cannot physically provide the same degree of isolation that the transformer does.

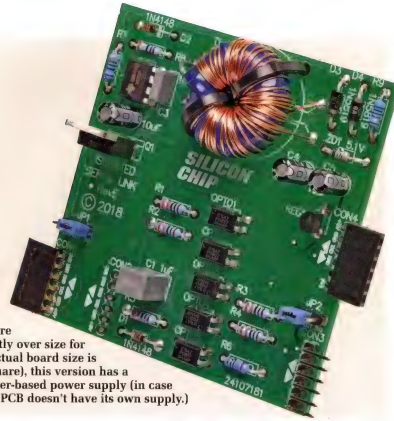
Making connections

To connect the external circuitry, the board has two connectors at the left and two at the right. All four have pin-outs that match the ubiquitous CP2102-based USB/serial module, available from the Silicon Chip Online Shop (**siliconchip.com.au/Shop/7/3543**).

One of the two headers on the left side usually interfaces with one of these USB/serial modules to connect to a computer.

This module can be plugged in or permanently soldered to the board, depending on your requirements.

On the other side of the board, one of the communications headers will accept a second CP2102 USB/serial module while the other can be used to plug in where a CP2102 module would. Alternatively, you can just wire up the RX/TX/GND serial connections using jumper leads.



Shown here significantly over size for clarity (actual board size is 74mm square), this version has a transformer-based power supply (in case the target PCB doesn't have its own supply.)

Why do I need one?

The advantage of having an Isolated Serial Link is that it allows bidirectional digital communications with no electrical path for current to flow between the two halves of the circuit. This can be handy if the two sides might be at different voltage levels, whether fixed or changing.

For example, let's say that you have designed a circuit which uses a microcontroller and some other circuitry, which is powered from the mains using a "transformerless" power supply with a current-limiting capacitor feeding a rectifier. This is quite common; many Silicon Chip designs use this arrangement.

But this makes it very difficult to debug your software since you have no way of getting feedback on what's happening in the microcontroller while it is powered from the mains; at least, not safely.

Besides the risk that you could have an accidental short between the incoming mains Active and a (supposedly) low-voltage connection, even something as simple as a mains cord or socket with swapped Active and Neutral wires (which is not uncommon!) could create a lethal situation.

But now, with the Isolated Serial Link, you can safely get serial data from the microcontroller, even if it's floating at mains potential, so you can see what it's doing.

It isn't just mains circuits where it's useful either.

For example, you might have a microcontroller with its positive rail connected to the positive terminal of a battery, for example, to simplify monitoring the current drawn from that battery via a high-side shunt.

If the battery bank is Earthed, you can't connect to the micro in the usual manner, as you will short out

Features & specifications

- Provides a fully electrically isolated, bi-directional serial link
- Galvanic isolation up to several hundred volts
- Baud rates up to 115,200
- 3.3V or 5V signalling at either end
- USB/serial interface module can be fitted at either end
- Powered from 5V (eg, a USB port)
- Can be built with isolated 5V & 3.3V supplies for the remote end
- Two isolated power supply options, either 100mA total or 200mA total

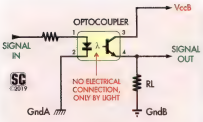


Fig.1: the traditional method of optoisolating a digital signal. When the input signal is high, current flows through the series current-limiting resistor and LED, lighting up the phototransistor, which pulls the output high. But using a resistor to pull the output low when the phototransistor switches off severely limits switching speed, allowing it to handle serial signals up to only 19,200 baud.

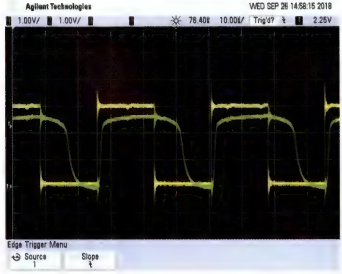


Fig.2: a scope grab showing the operation of the circuit in Fig.1. The yellow trace shows the input signal and the green trace, the output. Note that the output rise time is much shorter than the fall time, which stretches the length of the output pulse. The higher the signal frequency, the more this affects signal integrity.

the batteries (and that's a big no-no!).

But if you connect it via the Isolated Serial Link, that is no longer the case and you can communicate with and re-program that micro as usual.

An Isolated Serial Link can even be useful if both devices are nominally at the same potential.

If a circuit has more than one ground connection, there is the potential for a ground loop which can cause electrical noise, possibly interfering with the integrity of the serial data or other signals in the circuit.

The Isolated Serial Link avoids the introduction of an extra ground connection, thus eliminating the possibility of any ground loops being caused by the serial connection.

Isolating high-speed digital signals

The usual method of optocoupling a digital signal is to apply the incoming signal to the optoisolator's internal LED via a current-limiting resistor, then connect the output transistor either as an emitter-follower or as a common-emitter amplifier, with a pull-up or pull-down resistor respectively.

The common-emitter version of this method is shown in Fig.1.

When the input signal goes high, the internal LED switches on and the light it produces causes the output transistor to switch on, connecting the output to VccB and so pulling it high. When the input signal goes low and the LED switches off, resistor RL pulls the output signal line low, to GndB.

Because the output transistor is actuated by light, clear plastic between it and the LED provides a high degree of electrical insulation while still allowing signals to travel from one side to the other.

But there is a problem with this configuration: the output arrangement is not symmetrical – the transistor pulls the output up much faster than the resistor can pull it down. You can use a lower resistor value to speed it up but that increases current consumption and you can only lower it so far before you overload the output transistor.

A scope grab of this configuration operating is shown in Fig.2. The input signal is yellow and the output signal is green.

You can see how the pulse is stretched due to the slow switch-off time, despite a relatively low resistor value of 220Ω being used (drawing nearly 25mA when the output is high).

This signal distortion will prevent the receiving end from decoding the serial data above a particular data rate. The fastest baud rate we could achieve reliably with this arrangement was 19,200 baud.

The common-emitter version of this circuit would suffer from the opposite problem, ie, a slow switch-on, resulting in short pulses ("runts"). The outcome is the same: high-speed serial data will not pass through such a link.

A better method

To solve this without resorting to specialised high-frequency optoisolators, we are using pairs of optocouplers in a totem-pole configuration, as shown in Fig.3. One pulls the output high and the other pulls it low. That gives fast, symmetrical drive with a much-reduced supply current.

When the input signal is high, the upper LED is forward-biased and so current flows from VccB, through its output transistor and to the output signal line, quickly pulling it up. And when the input signal is low, the bottom LED is forward-biased and so its associated output transistor quickly pulls the output signal line low, to GndB.

Fig.4 is a scope grab of this type of circuit in operation and as you can see, the rise and fall times are now essentially symmetrical. While there is a delay of around 5µs, this will not affect serial decoding as the critical logic level thresholds are delayed consistently.

The 115,200 baud limit of this type of circuit is because the delay starts to extend into the next bit time, and at 230,400 baud (the next standard baud rate), the bits are just over 4µs wide, meaning the bits overlap and distort.

The only case where this delay might be a problem at lower baud rates is if the outgoing data is synchronised with the incoming data, either through system design or perhaps a carrier sense bus arbitration design, where the transmitter is listening in on the receiver to see that it has full control of the bus.

But that's a rare situation. For normal serial communications, the delay doesn't matter.

By the way, while it might appear

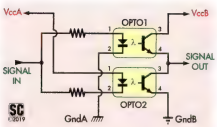


Fig.3: this shows the push-pull digital optoisolator configuration which we're using instead. It is a symmetrical arrangement of two optoisolators in a totem-pole configuration. When the input signal is high, the upper optocoupler conducts, pulling the output signal high. A low input signal activates the lower optocoupler, pulling the output low. This will pass a serial stream of up to 115,200 baud.

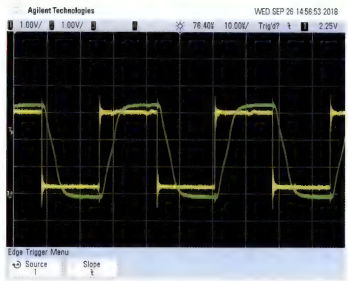


Fig.4: a scope grab showing the same signal as Fig.2 but using the coupling circuit shown in Fig.3. While there is a slight delay between the incoming and outgoing waveforms, the rise and fall times are now similar and short, so the signal can be properly decoded by the receiver at the output end.

that there is a risk that the supply rails could be shorted out if both optocouplers are switched on simultaneously (eg, with an open-circuit input), phototransistor current is limited to around 20mA by the light intensity generated by the LEDs.

With the input floating, the current through the phototransistors is around 4mA, which is insignificant.

Circuit description

The circuit diagram for the Isolated Serial Link is shown in Fig.5. Connections are made to the Isolated Serial Link at one end via either CON1 or CON2 and at the other end, via either CON3 or CON4.

We'll explain the reason for the pairs of connectors later. At the moment, it's easiest to ignore CON2 and CON4 and just consider the signals and power flow between CON1 and CON3.

Both ends are essentially interchangeable except for the power flow; CON1 receives 5V power to operate the circuit, between pins 1 & 2, while CON3 delivers 5V and 3.3V to any connected circuitry, at pins 1 and 6.

Power flows across the isolation barrier from left to right either via transformer T1 or isolated DC/DC converter module MOD1, depending on which is fitted.

Serial data signals pass in both directions in the manner described earlier, using optocouplers OPTO1-OPTO4.

Data delivered to pin 3 of CON1 appears on pin 3 of CON3 and data delivered to pin 4 of CON3 appears on pin 4 of CON1.

While these connectors can be wired to just about any circuit which uses TTL serial communications, the pinouts are specifically designed to suit the cheap and readily available CP2102 USB/serial bridges. So you can solder or plug such a device at either end of the circuit to provide a USB interface.

You can choose whether the serial signals at either end have a 3.3V or 5V swing, to suit the type of device that you're connecting. This is selected on the CON1 side using JP1, and with JP2 for the CON3 side.

Note that when you have one side operating at 3.3V and the other at 5V, the optoisolator drive currents are not the same in both directions but we haven't found this to be a problem – after all, you're usually applying the signal to a digital input pin on an IC, which has a very high input impedance.

Reset signal for micro programming

The fifth optoisolator (OPTO5) is used to pass the DTR flow control signal from CON1 to CON3.

This is often used with Arduino boards, to reset the micro and put it into bootloader mode, so that the chip can be reprogrammed without any additional user intervention.

The DTR signal from a USB-Serial converter is high when the device is idle and no communication is occurring and goes low for the duration of a transmission.

It does not just pulse low when data is being transmitted but is usually held low any time an application has the serial port open.

On typical Arduino boards, an RC network converts the DTR positive-to-negative transition from its onboard USB interface into a brief reset pulse. But this connection is not "broken out" for use with external serial ports or USB/serial converters. However, the $\overline{\text{RESET}}$ pin connection is available, so if we can generate this reset pulse from DTR, we can provide the same function.

That's precisely what D1 and its associated 10nF capacitor and 220Ω resistor do. Normally, with DTR high, the 10nF capacitor is discharged and the DTR pin on CON3 (pin 5) is held high by a 10kΩ pull-up resistor.

If the DTR pin on CON1 is externally pulled low, this pulse is coupled through the 10nF capacitor and it powers OPTO5's internal LED. Its associated phototransistor conducts, pulling the DTR pin on CON3 low briefly.

So if this is connected to the Arduino (or other micro's) $\overline{\text{RESET}}$ line, the micro will be reset.

C1 charges up quite quickly and so after a short time (around 1-2ms), OPTO5 turns off and the $\overline{\text{RESET}}$ line is released.

This is shown in scope grab Fig.6, with the DTR pin of CON1 shown in yellow and the DTR pin of CON3 in green. You can see that both traces drop to 0V around the same time but the green trace returns to a high level shortly afterwards.

The reset pin on an Atmega328 micro (as used in an Arduino Uno) only needs to be low for 2.5µs to guarantee a reset, so this pulse is more than adequate.

Note that this pulse must be shorter than one second for the programming sequence to complete correctly. D1 discharges the 10nF capacitor when the DTR pin of CON1 goes high again.

If this function is not required and you want to pass the DTR signal through the isolation barrier unaltered, simply replace the 10nF capacitor with a wire link.

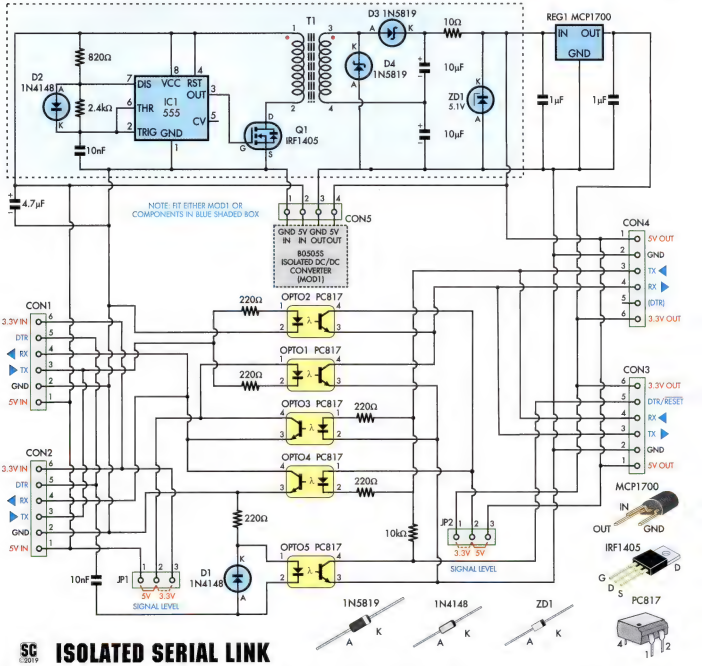
Isolated power supply

We've provided two means of getting power 'across the gap'. The simplest approach is to use a self-contained, isolated DC/DC converter module (MOD1), which has a 1kV isolation rating.

In this case, the components in the blue shaded box at the top of Fig.5 are not needed. The 4.7µF capacitor at left bypasses its input supply while REG1's 1µF bypass capacitor provides some output filtering for the module. REG1 at right is a 3.3V low-dropout regulator which provides a 3.3V rail for any circuitry connected to CON3 or CON4.

This is included since many USB/serial converters also provide a 3.3V supply and it's useful for powering certain microcontrollers or other circuitry.

As an alternative to using this module (eg, if you have trouble obtaining it), we have included the circuitry



SC ©2019 **ISOLATED SERIAL LINK**

Fig.5: this circuit of the Isolated Serial Link has the optional isolated power supply at the top (blue box). The alternative isolated DC/DC module which can be used instead is near the centre (grey box). The isolated bidirectional serial data link is provided by OPTO1-OPTO4. OPTO5 couples the DTR signal from left to right.

in the box at the top of Fig.5, which comprises a complete isolated power supply.

If these components are fitted, you do not need MOD1.

Timer IC1 is configured as an astable oscillator and it drives the gate of Mosfet Q1, which sinks current through the primary of transformer T1 in brief pulses. These induce pulses of current through the secondary winding, which are rectified using schottky diodes D3 and D4 to produce a ~6V DC rail, which is then regulated to 5V by zener diode ZD1.

IC1 uses pretty much the traditional method for a 555-based oscillator except that we've added diode D2 from pin 7 (discharge) to pins 2 & 6 (trigger/threshold) to reduce its duty cycle below 50%.

That's necessary to limit the output voltage at the secondary of T1 to an appropriate level and also to keep current consumption reasonable (around 100mA). IC1 uses a 10nF timing capacitor which is charged up via the 820Ω resistor and diode D2 when IC1's output pin 3 is high.

IC1's off time is determined by the 2.4kΩ resistor and 10nF capacitor, as the discharge pin (pin 7) goes low when output pin 3 is low, so the 820Ω resistor and D2 do not affect the capacitor discharge rate.

The result is a square wave with a high period of around 8µs and a low period of around 15µs, giving a frequency of around 40kHz.

Schottky diodes are used to rectify the output of transformer T1 to minimise power loss, as they have a lower forward voltage and faster switching than typical silicon types. The 5V rail at the cathode of ZD1 is not only fed to the 5V output pins of CON3 and CON4 but also to the input of regulator REG1, which as mentioned earlier, supplies the 3.3V output pins on CON3 and CON4.

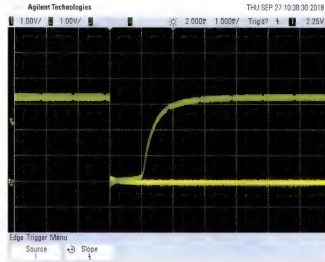


Fig.6: the yellow trace is the signal applied to the DTR pin of CON1 while the green trace shows the signal at the DTR/RESET pin of CON3. The falling edge of the DTR input generates a 1-2ms low pulse at the reset output, which can be used to reset the microcontroller in an Arduino-compatible board, activating its bootloader and allowing the chip to be reprogrammed.

Connector options

CON1 and CON2 are wired identically. They are both included to provide you with different options for making connections to the board. You would generally fit one or the other but not both.

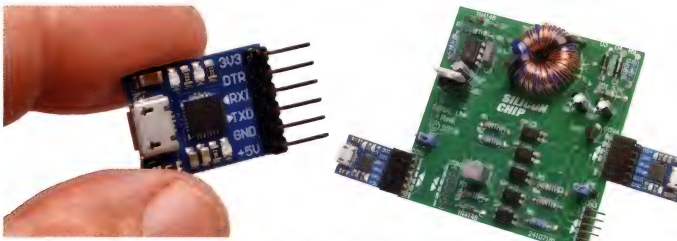
CON1 is near the edge of the board and you can fit a male or female six-pin header which may be vertical or horizontal (eg, using a right-angle type).

We recommend fitting a horizontal female header socket to CON1. You can use a vertical socket but bend its leads by 90° before fitting it. It is then possible to plug a CP2102 module fitted with a right-angle male pin header into this socket (see below). Or you can plug jumper leads into the header.

CON2 is placed further inboard and can be used when mounting a CP2102 USB/serial converter module directly on the board. In this case, you would fit a vertical header and then solder the CP2102 module on top.

Turning now to CON3 and CON4 on the opposite side of the board, these are arranged slightly differently. For a start, they are reversed compared to each other but also, the TX and RX pins are reversed between them.

So if you fit a male pin header to CON3 (ideally a right-angle type), it has the same pinout as a CP2102 module. So by fitting a CP2102 to CON1/CON2, the Isolated Serial Link is essentially "transparent" and you can treat it as a simple CP2102 module, but with the added isolation layer.



The Isolated Serial Link can be used as a "null modem" to allow communication between two computers. Note that two USB/serial converter modules are needed for this application. Since each side is supplied with power, the power transfer circuitry is also unnecessary.

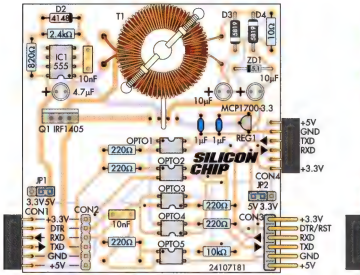


Fig.7: this shows where to fit the components for the version of the Isolated Serial Link which uses a transformer to provide isolated power to circuits connected via CON3 or CON4, drawing power from CON1 or CON2. This shows all four connectors fitted but you don't have to fit them all – and you can also use different types, to suit your application.

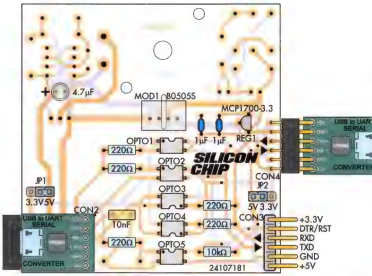


Fig.8: if you're building the version which uses the isolated DC/DC converter module (MOD1) instead of transformer T1 and associated components then you only need to fit the parts shown here. This time we're showing a CP2102-based USB/serial module mounted on the board via CON2 and another plugged into CON4 but that's just an example of how you can use it.

You could also fit some other type of header to CON3 and wire it up to another board using jumper leads.

Alternatively, you can fit a female socket for CON4 (right-angle preferred), you can then plug a CP2102 module in, potentially giving you a USB socket at both ends of the module.

That is why the TX and RX pins are reversed; the two sides can then communicate with each other normally.

This is a bit like the old "null modem" cables (remember them?) that allowed two computers to communicate via their serial ports.

Note though that if you do fit a CP2102 to the right-hand side of the module, it will provide the 3.3V and 5V supplies, so you should leave out all the power supply circuitry on the Isolated Serial Link board (including both T1 and MOD1) so that they do not try to "fight" each other.

In the absence of a commercial model, we wound our own transformer using a 5A 100µH toroidal inductor. After insulating the winding with tape, we wound on a secondary which matched the number of turns on the "primary".

Because the DTR/$\overline{\text{RST}}$ signal is not useful in this configuration, it isn't connected to CON4 at all. It's up to you whether you want to leave D1 and its associated capacitor and resistor off the board, since they won't be used.

Winding the transformer

Since we couldn't find a suitably small transformer for T1, we decided to make one ourselves, starting with a prewound inductor, which forms the primary. The secondary is then wound on top.

If you are building the unit with the isolated DC/DC converter module, you can skip to the next section.

Start with a 3A or 5A 100µH toroidal inductor (we used Jaycar Cat LF1270). Take a roll of electrical tape and cut it into lengths of approximately 250mm, then cut those in half lengthwise, so you have two thin strips.

The completed transformer is held in place on the PCB with a pair of small cable ties through the holes provided. Cut the excess from the ties on the underside of the board. Don't use wires to hold it in place because they could form shorted turns and seriously degrade performance.

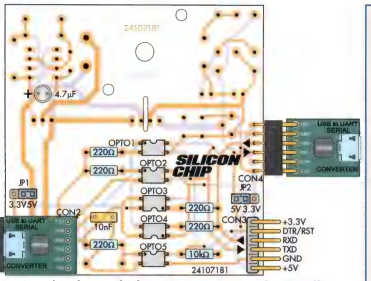


Fig.9: this shows which components you need to install if you're supplying 5V power to both sides of the board, and do not need an isolated supply to transfer power from CON1/CON2 to CON3/CON4. For example, you would use this configuration if you're connecting a USB/serial converter module at both ends, as shown here.

Wind those strips around the inductor with a slight overlap, forming a complete isolation barrier over the windings, except for two small areas where the leads emerge.

Next, cut a 2m length of 0.4mm diameter enamelled copper wire. It's important to start with the correct length; if it's too short you won't have enough wire, and if it's too long, it will be difficult to wind.

If you start with a different inductor, you may need to wind on a different number of turns and will, therefore, need a different length of wire. The number of turns you add should match the number of turns already on the inductor (which will become the primary winding).

Starting winding on the opposite side of the core to the existing leads, so that the tails will match up with the pads on the PCB. Leave about 25mm of free wire to connect to the PCB, then wind 50 turns on top of the existing windings, keeping them as tight as possible.

The direction of winding is unimportant, as the output is rectified.

When finished, cut the remaining wire to match the 25mm initial length, then scrape about 5mm of the enamel off the ends of the two leads and tin them.

PCB assembly

Fig.7 shows where to fit the components on the PCB for the version using the transformer to pass power across the isolation barrier. If you are building the version that uses the DC/DC converter module, refer to Fig.8 instead.

Fig.9 shows how to assemble the PCB if you have 3.3V or 5V DC power available at both ends of the Isolated Serial Link.

All three versions are built using the same PCB, which is coded 24107181 and measures 74 x 74mm. The following instructions describe fitting all the parts; ignore the instructions to fit any components which your version does not require.

Start by soldering the resistors in place. It's a good idea to check each value using a multimeter before fitting them, as the colour bands can be difficult to read. Be sure to trim all the leads neatly after soldering, as stray leads left over could potentially compromise the isolation barrier.

Mount the diodes next. D1 and D2 are small 1N4148 types while D3 and D4 are larger schottky diodes. They are all polarised, so check that each cathode band is facing as shown on the relevant overlay diagram before soldering it in place. Note that D3 and D4 face in opposite directions.

There is also one zener diode, ZD1, and now is a good time to fit it, with the orientation as shown. The five optoisolators can be mounted next. They are not all orientated the same way. OPTO1, OPTO2 and OPTO5 have their pin 1 facing the top of the board while OPTO3 and OPTO4 have the opposite orientation.

Line up the dots and notches on the optoisolators with the PCB and ensure they are sitting flush before soldering all the pins.

Parts List – Isolated Serial Link

1 double-sided PCB coded 24107181, 74mm x 74mm
2 6-pin female headers (CON1,CON4) [Altronics P5374]
2 6-pin male headers (CON2,CON3) [Altronics P5430, Jaycar HM3212]
2 3-way pin headers with jumper shunts (JP1,JP2) [Altronics P5430 and P5450 or Jaycar HM3212 and HM3240]

Capacitors
1 4.7µF 16V electrolytic capacitor
2 1µF MKT or multi-layer ceramic
1 10nF MKT

Semiconductors
5 PC817 opto-isolators (OPTO1-OPTO5) [element14]
1 MCP1700-3.3V LDO 3.3V regulator, TO-92 (REG1)
1 1N4148 signal diode (D1)

Resistors (all 1% 1/4W metal film)
1 10kΩ
5 220Ω resistor

Extra parts for version using MOD1 (optional)
1 B0505S-1W 5V-5V DC-DC isolated converter *or* LME0505SC [element14] *or* RFM-0505S [Mouser]

Extra parts for version using T1
1 100µH 5A toroidal powdered iron inductor (T1) [Jaycar LF1270]
1 2m length of 0.4mm diameter enamelled copper wire (for T1)
2 small cable ties
1 NE555 or equivalent timer IC, DIP-8 (IC1)
1 IRF1405 N-Channel Mosfet, TO-220 (Q1) [Jaycar ZT2468, Altronics Z1545]
1 5.1V 1N4733 Zener Diode (ZD1) [Jaycar ZR1403, Altronics Z0614]
1 1N4148 signal diode (D2)
2 1N5819 1A schottky diodes (D3,D4)
2 10µF 16V electrolytic capacitors
1 10nF MKT capacitor
1 2.4kΩ 1% 1/4W resistor
1 820Ω 1% 1/4W resistor
1 10Ω 5% 1/2W resistor
1 500mm length of electrical tape

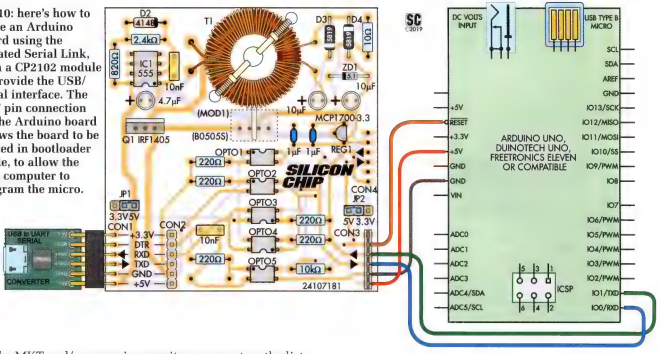


Fig.10: here's how to drive an Arduino board using the Isolated Serial Link, with a CP2102 module to provide the USB/ serial interface. The RST pin connection on the Arduino board allows the board to be placed in bootloader mode, to allow the host computer to program the micro.

The MKT and/or ceramic capacitors are next on the list. These are not polarised. Install them where shown, then mount small regulator REG1 with the orientation shown. You will need to bend its leads to suit the PCB pad pattern (eg, using small pliers).

Now you can fit the electrolytic capacitors, which are polarised. The longer lead is positive, so feed it into the pad marked with a "+" in each case. The stripe on the can is on the side with the negative lead. IC1 can be soldered directly to the board (preferred) or mounted using a socket.

Regardless, the notch in IC1 and the socket should face towards the bottom of the PCB. You may need to straighten the IC legs slightly so that they fit through the holes in the PCB or into the socket.

Next, fit the sockets for CON1-CON4. The exact arrangement used will vary depending on how you are planning to use the unit. If you are not sure, fit all the sockets as shown in our photos and on the overlay diagrams and then you have various options later. Figs.7-10 show some examples of various ways to use the board. At the same time, solder the two 3-pin headers for JP1 and JP2 to the board.

Solder the primary windings (made with thicker wire) to the pads on the left-hand side of transformer T1 with the thinner secondary connections on the right. Secure the transformer to the board using two cable ties, through the holes in the PCB.

If fitting DC/DC converter module MOD1, line up its outline with the footprint marked on the PCB, noting that the leads are closer to one edge than the other. The component markings should face towards the middle of the PCB. Solder it in place, keeping it flat and level.

Now mount Q1 with its metal tab facing towards the top of the PCB, as shown. If you like, it can be bent forward to sit parallel to the PCB. In this case, the tab will face up. No heatsink is required.

Using it

Before plugging it in, install the jumper shunts for JP1 and JP2 to match the voltage of the serial signals that will be applied to each side of the board. We found the 5V selection to work best for CP2102 USB/serial modules.

If in doubt, test the voltage of the TX line of the equipment you are planning to connect while it is powered but not transmitting. Serial data lines usually sit at a high level when idle, so this will give you an accurate reading of the voltage level.

Typically, you would connect a computer or other device which can supply power to run the circuit to the left-hand side of the unit (via CON1 or CON2).

If you have installed either T1 or MOD1, the unit can supply a modest amount of power to devices connected to either CON3 or CON4, up to around 100mA at 5V. This is enough to power something like a bare Arduino board but it will be overloaded if you try to power a board with a lot of extra accessories such as an LCD screen or motor.

In this case, you can power the circuit at the "remote" end using a battery pack, keeping in mind that if you wish to maintain isolation, no part of the two sides should be connected. In this case, you only need to make connections to the following pins on CON3/CON4: RX, TX, GND and $\overline{\text{RST}}$ (if needed).

It's always a bit tricky connecting the TX and RX lines between two boards because there are some cases where you connect the pin labelled TX to TX and other times when you connect TX to RX, depending on the labelling scheme used.

So to help remove some of the confusion, we've printed small arrows on the PCB (visible in Figs.7-9) which show the direction of data travel on each pin.

Treating the unit as an isolated CP2102 board

If you have a setup where you would normally use a CP2102 module to communicate with a device but you need isolation, you either plug a CP2102 module into CON1 (female header) or solder it to CON2. CON3 then provides a more-or-less identical function to the original CP2102 pins except for the added isolation layer.

So if you have a socket which will accept a CP2102 mod-

ule header, CON3 will have a matching pin-out and can be used as a direct replacement.

Connecting to an Arduino

This is especially helpful if your Arduino is connected to circuitry operating at much more than 5V (especially a battery which can supply a lot of current), or even mains. The isolation barrier will prevent any accidental shorts or component failures on the Arduino or any connected modules from damaging your computer.

In this case, we suggest you use the board with a CP2102 USB/serial module attached to either CON1 or CON2. Run jumper wires from either CON3 or CON4 to the Arduino board, connected as follows: GND to GND, RX to TX and TX to RX.

The reason why TX is not connected to TX and RX to RX is that the signal that is being transmitted by one side is being received by the other. This arrangement is shown in Fig.10.

To be able to reprogram the Arduino while it is connected over the Isolated Serial Link, you will also need to connect the pin labelled RST on the Isolated Serial Link to the $\overline{\text{RST}}$ pin on the Arduino.

Note that this will only work with Arduino boards that communicate via a USB-Serial IC which is separate to the main processor IC.

We have tested this on the Uno and Mega compatible boards but it will not work with boards such as the Leonardo because they do not expose their serial programming lines directly.

Boards such as the Nano should allow programming, as they use a similar designto the Uno and Mega, although we have not tested this.

Other Arduino variants may or may not work, depending on how they are configured.

Note that the power supply built around T1 may be able to supply enough power to the Arduino during programming but it's possible that it can't, as Arduino boards can be quite power hungry, even when doing nothing.

Using it to connect two computers

To provide an optoisolated link between two computers (or a computer and Raspberry Pi), you will need to connect two CP2102 modules to the Isolated Serial Link. Connect one to either CON1 or CON2 and the other to CON4.

Since both computers can supply power, none of the power transfer circuitry is needed. Note that the DTR/$\overline{\text{RST}}$ signal will not be used either, so OPTO5 and its associated components could be omitted.

Using other USB/serial converters

While the board was designed to suit CP2102-based modules, other types can be used. Note though that this unit has been designed to work with TTL level signals, and will not work with RS-232 voltage level signals.

Just make sure to set the correct voltages on each side and also connect the correct power and signal connections. Using jumper wires with socket ends onto the pin headers is an easy way to do this.

You can even use a minimal amount of cyanoacrylate glue (superglue) to join the socket ends of the jumper wires together, to create a removable harness. SC

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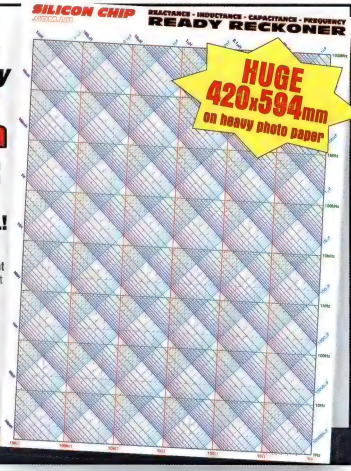

Altium CIRCUITMAKER

Aimed at "makers" and electronics hobbyists, CircuitMaker is *free* circuit and PCB design software, from the creators of professional PCB software Altium. In fact, if you have used Altium, you will find CircuitMaker familiar. If you haven't designed a PCB before, but want to, it's a great way to get started. This article goes through the all steps from installing the software to producing the files needed to manufacture your PCB.

We use Altium Designer for PCB design here at SILICON CHIP. You may recall our review of Altium Designer 18 in the August 2018 issue (siliconchip.com.au/Article/11189). But Altium also produces another piece of software named CircuitMaker, which is also EDA (electronic design automation) software but is targeted at hobbyists and "makers". And while Altium Designer costs quite a lot to buy, CircuitMaker is free!

While this sounds like a great deal, there are, of course, some restrictions. All projects are stored in Altium's "cloud" server, and are also available to be viewed by anyone who has a CircuitMaker account. Anyone can make a copy of someone else's project and add it to their own collection.

Such projects may also be subject to open-source licensing restrictions; these vary, but you may be required to make your design files available if they have been derived from another open-source project.

As you might expect, CircuitMaker does not have all the features that Altium Designer boasts. For example, it doesn't have support to simulate the circuit that you draw. But it still has pretty much all the features you need, including an advanced auto-router.

This is an introduction to using CircuitMaker, suitable for those who are new to EDA software.

We're going to assume that you're fairly comfortable with computer software in general, and we will point out some of the things we noticed along the way.

As with many Altium products, CircuitMaker is restricted to the Windows operating system (version 7 or later), although you can browse and view projects from the Circuit Maker website in a browser on many other platforms.

You might like to have a look at some of the projects that have been created by others now. These can be found on CircuitMaker's project page, at: https://circuitmaker.com/Project

A brief introduction to EDA

With a modern EDA tool, the design starts with a process called "schematic capture", ie, drawing the circuit diagram in CircuitMaker. It mainly involves placing components on the schematic and then drawing wires to connect them in the desired fashion.

While you are doing this, the software is generating a "netlist". Each connected group of wires is called a net and is given a unique designation (name). Circuit simulation programs also use netlist files; while CircuitMaker does not have this feature, Altium Designer 18 does.

Each component on the circuit is also assigned a "footprint". This is a representation of the physical component and is used in the later PCB layout stage.

A given component can have many different footprints associated with it (such as SOIC and DIP for an IC). While these may look the same in the schematic, they require different handling on the PCB.

Once the schematic is complete, it is transferred to the PCB layout editor, populating the blank PCB with all the required component footprints. These can then be dragged into place

Fig.1: the Layer Stack Manager tells CircuitMaker how the PCB is going to be assembled. This default view shows how a typical double-sided PCB is made. The Gerber files produced at the end of the process consist of one file for each of these layers, plus an eighth which dictates where holes are to be drilled.

on the PCB and connected by tracks and vias.

A design rules engine ensures that manufacturing tolerances are maintained (such as minimum track separation) and confirms that all nets have been properly routed.

The traces on the PCB can be routed manually or an auto-router can run the tracks automatically. While auto-routers keep getting better, they don't always produce ideal results.

The final stage is to export the project in a format which can be used to manufacture your design. These are typically in the "Gerber" format, which virtually all PCB manufacturers accept.

In the near future, we hope to do a review of the various ways that you can PCBs made, both at home and from fabricators who will do this for you. Gerber files can be used for all these methods.

A two-layer board, such as those we typically create at SILICON CHIP , will consist of eight files (usually bundled inside a zip file), each of which corresponds to a layer within the PCB layout editor.

When we speak of a two-layer board, we are referring to it having two conductive copper layers, one on each side of the dielectric (insulating) core, which is typically made from FR4 fibreglass (or Kapton film in a flexible PCB).

But there are also separate solder mask, drilling and outline (silkscreen) layer files. These additional files are used at different stages in the manufacturing process.

In fact, the various component footprints consist of not much more than a specific arrangement of shapes, such as circles and polygons, on the various layers.

A simple pad or via consists of a hole on the drill layer, a copper disc on the top and bottom copper layers, and a similarly sized hole in the solder mask, and may have, for example, a hollow circle defining its footprint on the overlay layer – see Fig.1.

Installing CircuitMaker

Before downloading and installing CircuitMaker to your Windows PC you need an Altium account, which in turn

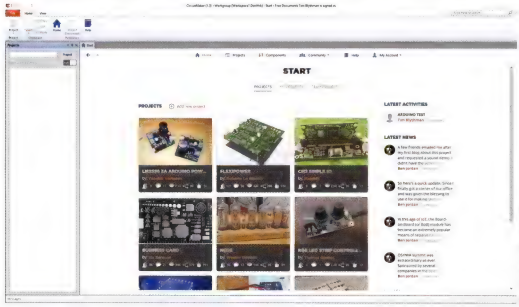

Fig.2: the CircuitMaker main page appears immediately after launching the software. You can browse other users' projects, and even make copies for your own use. Not surprisingly, the "My Projects" tab is where you will find your own projects.

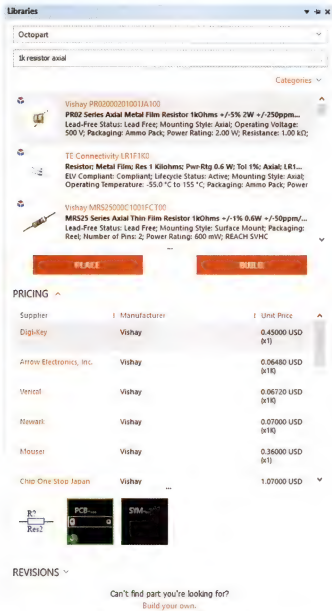

Fig.3: the Octopart library has a vast number of parts; we couldn't even count how many 1kΩ resistors there are. When choosing a component for use in CircuitMaker, make sure that it has a PCB footprint. The small black box with a green tick tells us this is the case for this part. Take care that the footprint matches the part you will actually use.

requires an email address. You can sign up for one at: https://workspace.circuitmaker.com/Account/SignUp This will send an activation link to your email, which validates your account.

You can then use your credentials to sign in at https://workspace.circuitmaker.com/Account/Login and click "Download" to download and then run the installer.

The installer has a long EULA (end-user license agreement) that you will need to agree to before proceeding and you will then be prompted to enter your Altium/CircuitMaker credentials before it installs. The version we installed downloaded another 660MB of files.

We normally keep our documents on a network drive, which the installer refused to accept, so we had to set our documents storage location on a local hard drive. It appears some local copies are kept in addition to the files kept on Altium's cloud server.

Once the installation is complete, open CircuitMaker and log in. The start page (Fig.2) lists your projects which are stored on Altium's servers.

Starting off with CircuitMaker

A CircuitMaker project consists of a main project file, which usually contains at least one schematic (.SchDoc file) and one or more PCB files (.CMPcbDoc). It may include other types of files too.

To begin, click "My Projects" on the Start tab, then click "Add New Project". Enter a name and description and choose whether it will be stored in the public folder or a private sandbox. You're allowed to have two files in the private sandbox, and these cannot be seen by other users. Anything in the public folder can be seen by other users.

If you like, you can find our "Simple Uno Clone" project and make a copy of it in your account by using the "fork" option.

If you are not sure, you may wish to start with the sandbox. You need to save and then open the project to start working on it. The project will appear in the "Projects" tab at left. From here, you can right-click on the project name, select "Add new to project" and click "Schematic".

Change the name if you wish, then press Enter. You are presented with a blank sheet onto which you can add components.

We found this stage was one of the more challenging, but also demonstrates the power of the cloud-based setup. There are literally millions of components to choose from, with many of them added by other users and available to everyone.

As with many open source projects, the quality of the user-added content varies. For example, when we were looking for header pins, we found a number that had been customised by other users for a specific role, rather than having a simple set of numbered pins.

Another example is that the capacitors we were using for one project contained elements on the board outline layer; if we had used these footprints as-is, the manufacturer would have cut a rectangle out of the board, leaving nothing but a hole for the component to mount on!

While many users, particularly those who sell their finished designs, may use specific parts from specific manufacturers in their design; however we often use generic parts in our design. For example, we may want to place a ¼W resistor which you can buy from any retailer. But we couldn't easily find a generic "¼ W resistor" component that we could use.

To add a component, you need to choose one from the many that are available. Pressing the component button on the ribbon opens up a dialog box, from which you can click the "Choose" button to open a search window. The search window is limited to 25 entries, which can be quite limiting.

It's more helpful to click the "View" ribbon button and select "Libraries". At the top of the panel that appears, you can select between "Favorites", "Octopart" and "Project". As you won't have any favourites yet, choose "Octopart".

Octopart is a company owned by Altium, mainly known for their website **octopart.com** which collects data from various suppliers (such as element14, Digikey and Mouser) which can then be searched in one place.

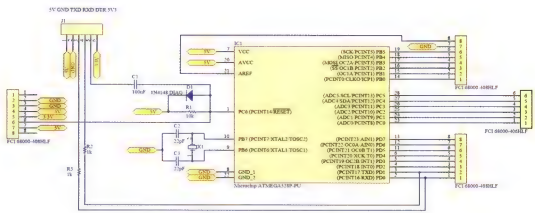

Fig.4: our completed schematic for a simple Arduino Uno clone. We have used ports (the yellow lozenges) for our power connections to simplify the appearance of the wiring.

We found it helpful to search on the Octopart website alongside the library view (Fig.3), as the specific manufacturer part numbers gave definitive search results.

The Library view gives a lot more information than the basic component window, and in particular, you can tell straight away whether a part has a PCB footprint available. This is important, as we cannot complete the PCB design without a component footprint.

We finally found what we needed by searching for "1k resistor axial" and selecting the first item in the list. Once you have found a match for your component, you can right-click it to add it to your favourites. When you've established a good set of favourites, you will not need to spend as much time searching for commonly-used parts.

Once you have found the part you need, click "Place" to add it to your schematic. The part appears under the mouse pointer and can be placed multiple times by clicking repeatedly. Stop placing components by pressing the "Escape" key. Once you have opened the library, you will notice it minimises to a small icon to the side of the window, and can be opened again by clicking on the icon.

Having placed a part, you will see that it has text above and below it. The upper text (initially "R?" for a resistor, for example) is the designator while the lower text is a comment, which is useful for extra information such as component values or IC part numbers.

Either can be edited by double-clicking and changing the "Value" parameter. In our case, we changed "R?" to "R1".

A component can be moved by clicking and dragging it, and if you press the space-bar while the mouse button is down, the component will rotate by 90°. Similarly, pressing "X" or "Y" will flip the part around the horizontal and vertical axes respectively.

Once the components have been added and roughly placed, wires can be added by selecting "Wire" from the home ribbon, or simply pressing "W" on the keyboard.

This follows an intuitive click and drag process, with the pointer lighting up with a red cross when a connection is ready to be made. As with the place command, pressing "Escape" will cease wiring. Many of the shortcut keys are worth remembering, as they are also used similarly in the PCB editor.

You can move components after they have been wired and the wires will generally remain attached to the components. A wire (or component) can be removed by clicking on it and pressing "Delete".

If you have wires that have many connections (power connections would be a typical example), you can add a "Port", found among the circuit elements. Any ports with the same name are considered connected, meaning wires don't have to snake all over the schematic.

Navigating around the circuit

You can hold down the right mouse button and move the mouse to move around the document, as though by dragging. Pressing <Ctrl> while scrolling the mouse wheel zooms in and out. You can also zoom in and out using the "View" menu.

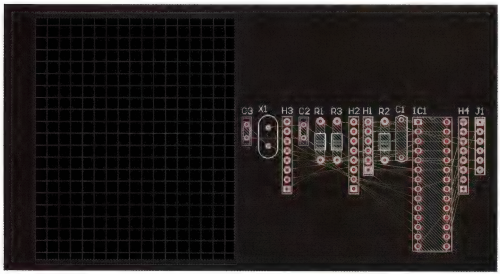

Fig.5: the so-called "rat's nest" that is visible at the start of PCB layout is always messy (hence the name), but clever component placement is the key to turning this into a working PCB.

These shortcuts can be changed by clicking on "My Account" from the Start page, and choosing "Preferences", and then select the System => General Settings option.

Creating a PCB layout

Once you have finished drawing the circuit (ours is shown in Fig.4), you can proceed to PCB layout. The first step is to create a PCB layout file (.CMPcbDoc) within your project. Right-click on the project name, select "Add New to Project" and click "PCB".

The next step is to transfer the components and netlist from the schematic to the PCB layout. This is done by selecting Project from the Home ribbon, and selecting "Update PCB document...", or by pressing Ctrl-F5.

This brings up a dialog box listing the changes that will be made to the PCB document. It's a good chance to review what changes are occurring, and you can untick any of the changes if you don't want them to affect PCB. Usually, though, you leave all options checked, and click "Execute changes".

If, for example, you notice during the PCB layout stage that you have made an error in the circuit, you can go back to the schematic, make the changes, and then use the "Update PCB document" option again to push the changes through to the PCB layout. This is important, as later when we come to check that the PCB is fit for manufacture, everything needs to be consistent.

You will now find your PCB document contains a jumble of part footprints that need to be rearranged and connected (see Fig.5). It is said that most of the work in PCB layout is placing the components correctly, so it pays to take your time and organise the components well.

The components are connected by fine lines which show where a connection needs to be made. This is often referred to as the "rat's nest".

Ideally, you should place the components to minimise the length of these links, and also how many times they cross (as it's not always easy to cross traces on a PCB). As in the Schematic editor, you can use the space bar, X and Y key to rotate and flip the components as you move them.

CircuitMaker, like Altium, has a good set of keyboard shortcuts, and we often find that we have our left hand of the keyboard and right hand on the mouse as we work with these programs (you would do the opposite if you are left-handed).

Routing tracks

To manually lay track, click on the "Route" button on the Home ribbon, then click on the PCB to start the track. Typically, a track will run between two or more components, so it makes sense to start on a component. Clicking again will 'lock' the track so that if you need to route it around another component, it won't collapse on itself.

Keep going until you have clicked on an endpoint, then click one more time and press "Escape" to finish routing the track. You will notice that the program automatically avoids conflicting paths and pads, and it will follow a neat 45° path along the way.

Much of the cleverness of routing comes from it automatically trying to enforce design rules (such as track spacing in this case) as the routing occurs. Altium refers to this as interactive routing.

The layer tabs are useful during the track layout stage, as

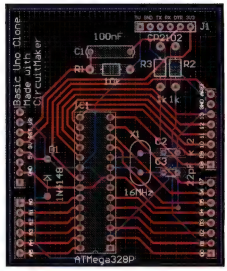

Fig 6: the simple Uno Clone, after it has been routed. The top copper layer is shown in red and the bottom copper layer is blue. The colour codes can be seen at the bottom of the PCB editor window and you can change them if you want to.

you can switch between layers easily. Pressing "*" on the numeric keypad will toggle between top and bottom copper layers, and if pressed while laying a track, will place a via to allow the trace to continue on the other side of the board.

Another useful design rule which you may wish to change, especially for high current designs, is the track width. The track width design rule consists of a minimum, preferred and maximum value. During track routing, pressing "3" will cause the currently laid track to cycle between these widths, allowing you to quickly lay a combination of power and signal tracks.

If you wish to try the Auto-router, switch to the Tools ribbon and click "Autoroute". The default setup is fine, so you can select "All". We'd recommend selecting "Lock all pre-routes" so that any tracks you have already laid will not be changed. Finally, click "Route All".

To stop the Auto-router, press the "Stop" button on the ribbon. Ctrl-Z (undo) can be used to revert, if you find the layout isn't to your liking.

We usually don't use Auto-route much, except to check if a component layout is routable. We find that if the computer can complete the routing, a human will do a neater job (see Fig.6).

PCB size and shape

The board size and shape can be changed at any time, and can be done in several different ways from the "Board Shape" option on the Home ribbon. "Redefine Board Shape" allows you to draw the outline of your board using the mouse pointer, while "Edit Board Shape" allows the existing shape to be tweaked by dragging the existing edges and corners.

If you need to create a complex shape, you can compose it from lines and arcs. At the bottom of the PCB editor, there are small tabs representing all the layers. Select the "Outline" layer, then use the line and arc tools under "Place" to draw the outline. Under "Clipboard", click Select, then "all on layer". Finally, select Board Shape and Define from

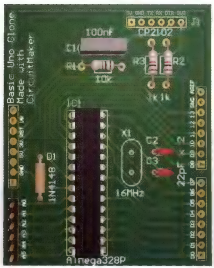

Fig.7: the 3D rendering is a great tool for visualising that the PCB looks 'right', but there are some limitations. If a component does not have a 3D body associated with it (like crystal X1), then the component won't appear. On the other hand, the footprints of the headers we are using are suitable for male or female parts to be fitted. Note also that the rendered diode body lacks a cathode stripe.

Selected Objects.

A 3D view of the PCB

The PCB 3D view (see Fig.7) can be a handy tool as you are working on the board. You can't do any editing in 3D mode, but it helps you to visualise how the PCB is coming together. You can get an idea of whether there would be issues with assembly due to the components being too close and so on.

You can enter 3D mode by pressing "3" on the keyboard, and return to 2D mode with "2". Panning is the same as 2D mode, and is done by right-clicking and dragging, while rotation is achieved by shift+right-clicking the mouse.

Much of the 3D content (such as component shapes) is from the community, so you may find that not all your components appear as you would expect. If you feel that some of this content could be improved, CircuitMaker provides the means for users to add things like footprints and 3D shapes to components.

Design rules

Another important item to consider at this stage is the Design Rules (see Fig.8). The "Design Rules" button on the Home ribbon is used to set the rules while the "Design Rule Check" option is used to verify that your PCB meets the rules.

The Design Rules are the criteria used to confirm that a board can be successfully manufactured. For example, a board manufacturer might specify that they can produce tracks down to 8 mils in width (0.008"), with a spacing of 10 mils. If you run a track that's smaller than this, or closer than that, the board you get back may be faulty. So you want the software to alert you if that is the case.

The default design rules are quite conservative, so that even a layout that falls afoul of some of these rules can probably be manufactured. Most board fabrication firms publish their design rules, so you can set them correctly in your software.

While ideally you should set the design rules up correctly from the start, you certainly can lay out a board and then adjust the rules later. A Design Rule Check will then indicate which areas of the board need attention.

You can apply complex rules to certain parts of the board instead of the whole. These can apply to certain nets, for example, to require thicker tracks for those that carry higher currents, or to require more spacing to provide isolation from high-voltage traces.

To take advantage of the Design Rules, click on "Design Rule Check", and then click "Run Design Rule Check" in the window that appears. You will have a list of 'violations' appear. If this list is empty, all is well.

If you have not finished routing, you should see a number of "Un-Routed Net Constraint" violations. This just indicates that there are no tracks joining points which should be joined, and the layout cannot be considered complete.

One constraint which we had to reduce on our design was the "SilkToSolderMaskClearance" constraint, which is the separation between objects on the silkscreen overlay from holes in the solder mask. The problem is that many footprints contain violations of this rule, so you cannot fix them by changing the layout. You would have to edit all the components to eliminate the errors.

Manufacturers generally fix this for you anyway, removing any silkscreen lines which intersect with holes in the solder mask.

It's a good idea to ensure that the design rules are fully satisfied before exporting the board. This may require rerouting or rearranging the board, or even modifying the design rules to suit the actual design rule limitations of the board fabrication process. Otherwise, you might get complaints from the manufacturer, or in the worst case, boards which don't work.

Exporting to Gerber files

As well as saving the individual files, you also have the option to 'commit' the project. This is part of the in-built version control that CircuitMaker provides; there is also an option to revert a project to an earlier stage.

Before producing Gerber files, you may be required to commit your project.

Once the board is laid out and all the design rules are satisfied, the board can be exported. We prefer to use a two-step process. The first step exports all files except for the drill holes, and the second part exports a file with the drill holes. The reason for this is that the standard drill file format is slightly different than the others (it's known as "Excellon").

The following export settings work with a number of the board fabrication firms we have tried, but yours may differ. Since the Gerber exporter for CircuitMaker is nearly identical to Altium Designer, any published settings for Altium Designer should work fine.

From the PCB layout document, click the "Output" ribbon, and then "Gerber". On the dialog box that opens up, work through the tabs from left to right.

On the General tab, select Inches and 2:5 format. On the Layers tab, select Top Overlay, Top Solder, Top Layer, Bottom Layer, Bottom Solder, Bottom Overlay and Outline.

These should be seven of the first nine items, skipping the two Paste layers. The Paste layers are needed for solder paste masks, which you generally don't need unless you

Fig.8: rules, rules, rules! The design rules are essential in ensuring that your design can be manufactured. Helpfully, the small diagram indicates where the constraint applies. The rules for your board fabricator may not match CircuitMaker's defaults but it doesn't take long to change them to suit.

are having your board fully assembled.

Skip the Drill Drawing tab; we will export a separate drill file next. On the Apertures tab, ensure Embedded Apertures is ticked, and on the Advanced tab, the "Generate DRC Rules export file" should be unticked.

Click OK, and a save dialog box will appear. Save the file in a known location. The Gerbers are saved as a zip file containing the individual layer files, and we will have to add the drill file later.

Windows 10 natively supports working with zip files, although we have long used the 7zip program for working with zip files too.

To generate the drill file, click on "NC Drill Files" on the Output ribbon. As for the other files, ensure that Inches and 2:5 format are selected, then click OK, and save the file in the same location. You should have two zip files with similar names.

The final step is to add the drill file into the zip which already contains the other Gerber files (see Fig.9).

Checking the Gerbers

Before sending the files to a manufacturer, it's a good idea to check them by viewing them with software like gerbv (**http://gerbv.geda-project.org/**). This was how we spotted the errant board outline strokes from our dodgy capacitor footprints.

Simply extract all the files and then open them one at a time in gerbv. You can assign preferred colours and switch layers on and off.

Ordering the boards

You can then send the Gerber files to be manufactured. Many fabricators provide an online Gerber viewer service. We recommend using this to check that the file appears as you think it should. It's a good sanity check that the files you have created are compatible with the fabricator's systems.

There are many PCB manufacturers, both here in Australia and overseas, who offer low-cost options for low quantities. Several of these advertise regularly in SILICON CHIP, either in display ads or in "Market Centre".

We haven't had the opportunity to try all of them but we would be very surprised if they couldn't all handle your Gerber files.

We suggest emailing the manufacturer(s) to check out their pricing for one-off PCBs of the size you are considering.

If you have placed the project in your public CircuitMaker

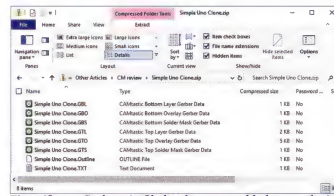

Fig 9: if your Gerber zip file has been assembled correctly, it should look something like this. There should be eight files with the file extensions shown (or similar). For some reason, Excellon NC Drill files usually have a .TXT extension (all Gerber files are essentially text files anyway). Your system may show different file types if these files are associated with a different program.

folder, you may wish to publish photos of the completed board or circuit to encourage others to use and improve it. You may even find other users can suggest improvements; this is one of the great advantages of the collaborative nature of open source software in general.

Conclusion

So you can see from the above that you get many of the useful features from Altium Designer but don't have to pay a lot of money to do so. The old adage "you get what you pay for" is definitely not true with CircuitMaker!

While the package is fairly intuitive after you have had some time to familiarise yourself with its interface, there is extensive documentation available. To answer any questions you may have, check out the docs, including a sample project walk-through, at: **https://documentation.circuitmaker.com/** SC

Can you export a CircuitMaker file for use elsewhere?

The short answer is yes . . . but in some cases there may be a little work required.

In general, you simply open the project in CircuitMaker and on the Project ribbon, click 'Release Project'. Select at least one output from the list presented and click Release.

Now, when you view the project on either the CircuitMaker website, the 'Release' can be found under 'Components and Releases' for that project. Click the download button to download a zip file of the project.

The zip file contains the design files inside a 'Design' subfolder, and the exported files in the 'Released' folder.

To open in Altium Designer:

If you wish to open the files in Altium Designer, make a copy of them. The .SchDoc schematic file can be opened directly, while the .CMPcbDoc will need to be imported.

To import in Altium Designer, click File=>Import=>Altium PCB, and browse to the .CMPcbDoc file and open it.

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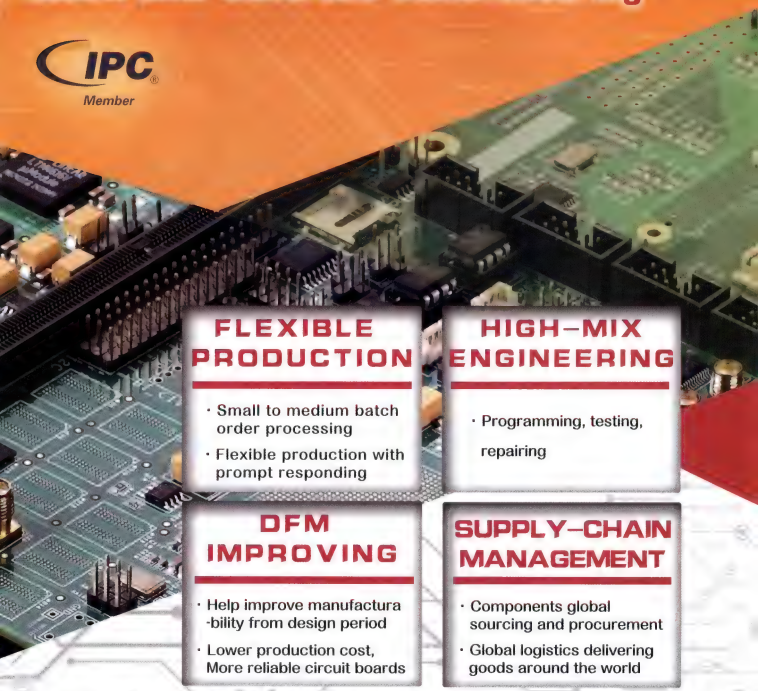

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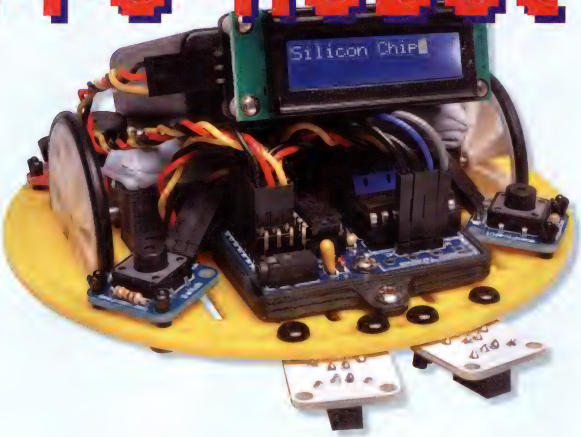
The PicoPi Pro Robot



Here's one for kids from 7 to 77; whether a raw beginner or a dab hand! It's a small, two-wheeled robot which you put together from a kit, then program to perform a variety of tasks. For example, you can get it to follow lines, detect edges, play music and much more. They'll "learn by doing" using a visual programming language and an inbuilt LCD screen. It's a great school holiday project but will keep them entertained all year!

- Can move in eight directions
- Play complex musical tunes with the piezo buzzer
- It can be up and running within a day of work
- 8-bit PWM motor speed control (0-255 steps)
- In-circuit programming with visual programming language
- Powered from four AA cells
- Line, edge and wall detection
- Good for beginners to electronics

By Bao Smith

To build the PicoPi Pro robot, you need to do some basic soldering, a little bit of mechanical assembly and some simple programming. It is a good project for children 7-8 years and older.

This kit would make a good gift for someone who wants to get into microcontrollers and robotics but doesn't want to learn C/C++ or Python programming languages (as would typically be used with an Arduino or Raspberry Pi-based robot).

It consists of about seven different modules which can be built separately and then combined to form the final robot.

The total cost is $110.00 (or $93.50 without the LCD module) and it can be built and running within a day. You'll need a soldering iron, side cutters, glue, Blu Tack, four AA cells and a programming cable.

The micro is supplied pre-programmed, but you need to use a programming cable to load software onto the robot so it can perform different actions.

The latest version of the kit can be programmed using a PICkit 3 or similar via a 5-pin male header, and we would recommend that you take that approach since you will then have a programming tool that's suitable for other uses.

The slightly older version of the kit that we built is instead programmed using a proprietary USB programmer that connects to a 2.5mm 4-pole jack socket on the robot. This programmer costs $26.40 as a kit or $41.03 pre-made.

Either way, the programming is done "in-circuit" (ie, with the robot completely assembled), making it easy to experiment with the robot.

Building the modules

All the parts come organised in individual bags, as separated in the parts list. You will need a soldering iron with a fine-tip and a Phillips head screwdriver, plus a pair of side cutters to trim the leads after soldering the components.

When soldering, it's generally best to start with the items that have the shortest pins or pin spacings, as these are more difficult to solder if the board is already partially populated.

Polarised components

Some components are polarised and it does matter which way around they are placed in the circuit. This includes the one diode, the LEDs, the tantalum capacitors and the ICs.

The diode has a black stripe at one end marking its cathode and this is lined up with the white stripe printed on the PCB where it is soldered.

Each LED has one shorter and one longer lead. The longer lead is the anode (+), and the shorter lead the cathode (-). Make sure the cathode goes to the square hole on the PCB.

Make sure the notch on both the IC socket and the IC matches what's shown on the PCB.

The tantalum capacitors are polarised and will be printed with a stripe on the body, indicating the positive lead (which may also be longer). So when fitting these capacitors, the positive lead goes into the pad closest to the positive symbol printed on the PCB.

When soldering the components to the PCBs (printed circuit boards), many of them are not polarised and so it does not matter which way around you place them.

Parts List

All components listed here are included in the PicoPi Pro Robot Kit, available from PicoKit (www.picokit.com.au; phone (07) 5530 3095), for $110 inc GST and P&P

1 circular piece of laser-cut acrylic, 125mm diameter
2 wheels with rubber tyres
12 M3 x 10mm plastic pins
12 M3 x 10mm screws
8 M3 hex nuts
2 velcro strips
2 metal gear 300rpm motors with semi-D shafts
2 motor housings
1 plastic case for the driver module
1 large steel bearing ball & housing
1 16x2 backlit serial LCD module
1 3-wire cable with plugs at each end

Driver module
1 driver PCB, 45 x 28mm
1 PIC16F506-E/P microcontroller
1 L293D motor driver IC
1 1N4148 small signal diode
1 1µF 25V tantalum capacitor
1 180kΩ resistor
1 4 x AA battery holder
1 2.5mm jack socket
1 16-pin DIL IC socket
1 14-pin DIL IC socket
1 3-way screw terminal block
1 3x7-pin header
2 4-pin header
1 3-pin header
1 jumper shunt

Microswitch modules (makes two)
2 microswitch PCBs, 20 x 11mm
2 snap-action microswitches
2 10kΩ resistors
2 3-pin right-angle headers
2 3-wire cables with plugs at each end

Photodiode & IR LED modules (two)
2 photodiode sensor PCBs, 20 x 20mm
2 3mm photodiode sensors
2 3mm infrared LEDs (940nm)
2 photodiode/LED plastic holders
2 330Ω resistors
2 10kΩ resistors
2 3-pin right-angle headers
2 3-wire cables with plugs at each end

Pushbutton modules (two)
2 pushbutton PCBs, 20 x 20mm
2 12mm tactile pushbutton switches
2 10kΩ resistors
2 3-pin right-angle header
2 3-wire cables with plugs at each end

Potentiometer module
1 potentiometer PCB, 20 x 20mm
1 50kΩ linear potentiometer & knob
1 3-pin right-angle header
1 3-wire cable with plugs at each end

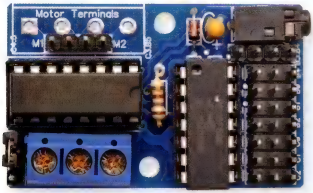
Buzzer module
1 buzzer PCB, 25 x 25mm
1 17mm piezo buzzer
1 BC327 PNP transistor
1 2.2µF 16V tantalum capacitor
1 10kΩ resistor
2 4.7kΩ resistors
1 3-pin right-angle header
1 3-wire cable with plugs at each end

LED cables (two)
1 5mm blue LED
1 5mm red LED
2 180Ω resistors
2 2-wire cables with plugs at each end

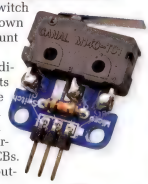
You will also need the PicoFlow USB programmer, PICkit or similar, four 1.5V AA cells, glue and/or Blu Tack.

Building the robot

Step 1: assemble the driver module, fitting the parts where shown on the PCB.



Step 2: assemble the two microswitch modules, fitting the parts where shown on the PCB. The microswitches mount on the edges of the two boards.



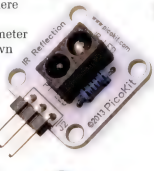
Step 3: assemble the two photodiode/IR LED modules, fitting the parts where shown on the PCB. Feed the photodiode and LED pairs through the plastic mounting blocks and ensure the LED orientation is correct before soldering them to the PCBs.

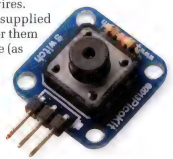
Step 4: assemble the two pushbutton modules, fitting the parts where shown on the PCB.

Step 5: assemble the potentiometer module, fitting the parts where shown on the PCB.

Step 6: assemble the buzzer module, fitting the parts where shown on the PCB.

Step 7: assemble the two LED cables. Cut one of the leads of each cable in half. Then strip 5mm of insulation off the wires. Then trim the leads of the supplied 180Ω resistors short and solder them to the exposed ends of the wire (as shown below).





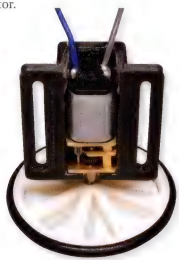
You will end up with two cables with resistors soldered into the middle of one of the wires. Twist the wires together and plug the LEDs into one end of the cable, with the shorter lead (negative) going to the wire you soldered the resistor onto. You can trim the LEDs leads if you want, but make a note which lead is the negative (cathode).

Step 8: peel the protective film off both sides of the laser-cut circular acrylic base.

Step 9: attach the driver module to its open plastic case, using two short (~4mm) self-tapping screws.

Step 9: attach the driver module (in its case) to the middle row on the base, using two short M3 machine screws and nuts. The notch for the programming socket should be seated near the outer rim of the acrylic base.

Step 10: take the spare 2-wire cable and cut it in half, then remove the insulation to expose about 5mm of wire. Heat and apply a small amount of solder on the ends of the wire (tin them) and then push them through the holes in the tabs on the back of the motor and solder them in place. Do this for both motors. When soldering apply heat for only a short period, so that the soldering iron doesn't burn the plastic on the motor.



A pair of side cutters is the safest way to cut the off the end of the motor housing. The motor should fit tightly in the housing, otherwise use a file to widen it slightly.

Step 11: the plastic motor housings supplied are a bit small to fit the motors. Use side cutters to completely open up the rear of each housing, where the vertical slot is located (see photo above). That will give enough room for the rear of the motor to fit and for the motor wires to poke out.

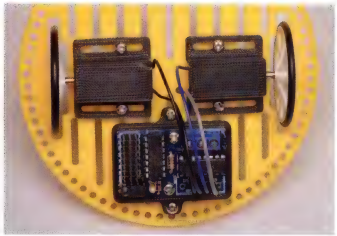
Once you've cut the unnecessary plastic out, you can use sandpaper or a small file to smooth the edges and widen the motor housing slightly.

Step 12: place the rubber tyres over the two wheels and then push the wheels onto the motor shafts.

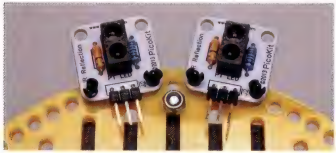
Step 13: place the motor into the housing so that it fits flush. You might need to force the motor in to get it to fit. Apply a small amount of silicone sealant or glue to the wires so that they are attached to the inside of the housing, preventing the wires from moving around and breaking the solder joints.

Step 14: attach the completed motor housing to the base using two screws and nuts each. The wheels fit through the wide slots near the edges (see photos).

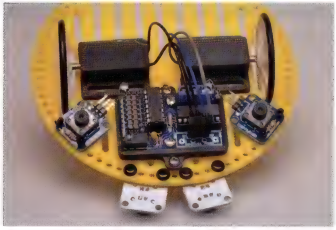
Step 15: attach the leads from the two motors to the headers on the driver module labelled M1 (left wheel) and M2 (right wheel). Don't worry about the orientation at this stage, since if one wheel runs backwards, you can easily swap them around later.



Step 16: push four of the plastic pins into the holes around to outer rim of the base so that the photodiode & IR LED modules can be attached to the underside, as shown in the photo below. We suggest you attach the two modules close to the driver module with the pin headers facing inwards, as we did.



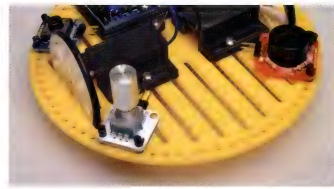
Step 17: using four more plastic pins, attach the two pushbutton modules on the top side of the base, near the wheels, facing inwards. You will need to bend the pin headers up slightly so there is enough space to plug the connecting leads on later (see below).



Step 18: attach the buzzer module on the opposite side of the right-hand wheel using two more plastic pins, as shown in our photos.

Step 19: attach the potentiometer module, on the opposite side to the buzzer module (behind the left wheel), using the same method.

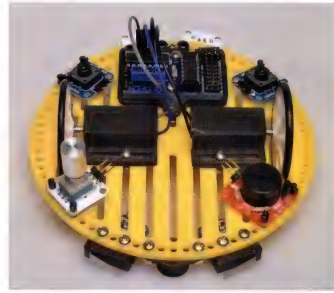
Step 20: push the steel bearing ball into the supplied housing (as shown directly right) as it provides extra support for the robot. It should be held in with friction.

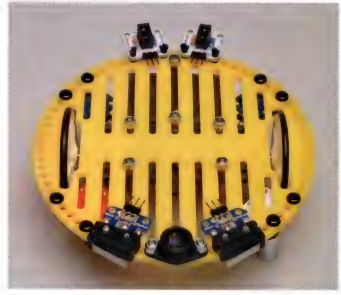


Step 21: attach the ball housing to the underside of the base, opposite the driver module, using two screws and nuts (see photo below).

Step 22: attach the two microswitch modules to the underside of the base, one on each side of the bearing ball, using two screws each. Note the orientation of the switches in our photos. The switch levers should face towards the centre.

Step 23: now everything can be wired up to the headers on the driver module. Fig.1 shows where each lead goes





and also indicates the wire colour which should go to each pin. Start by wiring up the buzzer, pushbuttons, potentiometer, LCD, LEDs and motor connections.

Note that you will almost certainly end up with a mass of wires above the driver module. It can't really be avoided (see photo below).

In each case where there is a 3-wire lead to plug into a separate board, plug it in with the yellow wire closest to the square mark on that board. The exception is the photodiode/IR LED modules, where the yellow wire goes to the pin marked J2.

To keep the wiring relatively neat, it's a good idea to feed the leads between the two motor housings and pull the loose ends back towards the bearing ball end of the base.

Note that two of the 3-wire leads pass from the top side of the robot to the bottom, through the slots, and connect to either the photodiode/IR LED modules or the microswitch modules, or a combination of the two, depending on which you want to use.

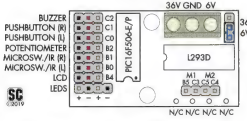
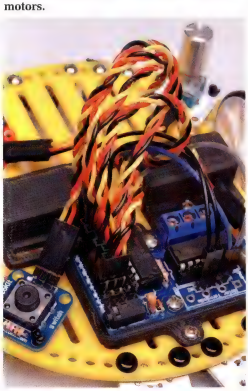


Fig.1: connection diagram for the PicoPi Pro Robot. Note the colour code on the seven 3-pin headers as they must match with the provided wires. The 36V connection is not used here – it's only used to power larger motors.



Step 24: determine how you will mount the battery holder so that you can access the on/off switch, replace cells and fit the LCD screen. We attached the battery holder to the top of the two motor housings using a stick of Blu Tack split in half to create two rectangular stacks (see lead photo).

The LCD screen is then attached to the front of the battery holder using the supplied velcro strips. I arranged it so that the power switch was facing up and next to the potentiometer module.

You may be able to attach the battery holder using velcro as well; it all comes down to how your wiring is arranged.

A more attractive method might be to cut two small wedge-shaped pieces of timber of around 15mm x 15mm, with a height varying between about 10mm and 13mm. These could then be glued to the top of the motor housings, with velcro glued on top of the timber strips, to attach the battery holder.

Step 25: glue velcro to the back of the LCD module and glue the matching piece to the battery holder. You may find that bending the 3-pin header on the LCD module makes attaching the wire lead easier. Plug the other end of the wire onto the driver module as shown in Fig.1.

Step 26: before attaching the battery holder, connect the red and black wires from the battery pack to the screw terminals on the driver board. As shown in Fig.1, the red wire goes to the terminal next to the jumper (6V), while the black wire goes to the middle terminal (GND).

Step 27: place the jumper shunt on the 3-way pin header next to the screw terminals, in the position closest to the nearby IC. This selects low-voltage (ie, battery) operation.

Step 28: insert four AA cells into the battery holder, making sure it's switched off beforehand. Then attach the battery holder to the PicoPi Pro Robot. We found with our battery holder that it took quite a bit of force initially to get it to switch on properly. Be sure to give it a strong push if the LCD doesn't light up.

Step 29: the two LED cables are optional. You can place the LEDs wherever you want to. If fitting them, plug the wires side-by-side into the 4-pin header next to the programming interface on the driver module, with the polarity shown in Fig.1 (if they don't work when you try them later, it's easy to reverse the plugs).

The Robot assembly is now complete and it's time to program it to do something useful!

Programming

The PicoFlow USB programmer from PicoKit plugs into a spare USB

What does each module do?

Driver module – powers and controls all the other modules via digital and analog signals. Also controls motor speed and direction.
Microswitch module – detects when the Robot bumps into something.
Photodiode & IR LED module – detects whether the surface beneath the sensor is light or dark. This allows the unit to pick up and follow dark lines beneath it.
Pushbutton module – gives you a way to control the Robot directly, eg, start or stop a program or manually move it in one direction or another.
Potentiometer module – can control the motor duty cycle via PWM (or some other parameter in your program).
Buzzer module – can be used to play sounds/music.
LED cables – use the red and blue LED to indicate status, as headlights or just to make the Robot look nice.
LCD module – displays debugging details and text.

Resistor Colour Codes

No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑ 7	10kΩ	brown black orange brown	brown black black red brown
❑ 2	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❑ 2	330Ω	orange orange brown brown	orange orange black black brown
❑ 2	180Ω	brown grey brown brown	brown grey black black brown

port and is supplied with a 4-pole 2.5mm jack cable which plugs straight into the driver board and allows you to reprogram the onboard micro directly from their PicoFlow Alpha visual programming software.

If you have the later version of the PicoPi Pro Robot with the 5-pin programming header, and a suitable programmer like the PICkit 3, you don't need the PicoFlow programmer.

The PicoFlow Alpha software is available for Windows only and can be used for free for two years. You can download it from the link at the bottom of this web page: **siliconchip.com.au/link/aamb**

Once you have installed this software, launch it and we are ready to write our first program. It's best to start with something basic. For example, one which sets the micro's output pins to a static state which causes the motors to run, eg, causing the Robot to rotate in place.

Having launched the PicoFlow Alpha software, double-click on the "output tool" (which looks like a blue microcontroller). A window will appear, as shown in Screen 1. This lets you set the pins to a high or low state.

Screen 1 shows the simplest example program you can run on the PicoPi Pro Robot. The program has just two elements, the "Start" tool, which looks like a traffic light, and the "Digital Output" tool, which looks like a microcontroller.

The PicoFlow USB programmer will need to be used to program the PicoKit if your robot only has a 2.5mm socket. Otherwise, you can use a PICkit 3 or similar.

Drag and drop components from the left-hand pane to the central pane to create this program. Then double-click on the Digital Output tool to set the output states.

In our example, we have pin C4 set to high which causes the left wheel to rotate forward, making the PicoPi Pro Robot move in a circle. The motor control pins are as follows:

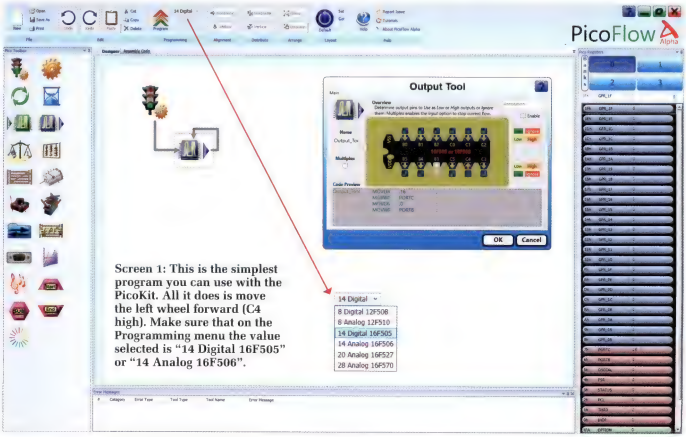
C3 high – right wheel forward
B5 high – right wheel back
C4 high – left wheel forward
C5 high – left wheel back

Leave all the other pins in a low state. For example, setting C3 and C5 both to high will make the Robot rotate in-place.

Once you've finished setting up the output states, make sure that its "output" is fed back into itself so that the program will keep the outputs in that state forever.

You can right-click on the Assembly Code tab at the top of the window to export the program as an ASM or HEX file, but note that the HEX files produced by this program cannot be read by MPLAB IPE. So you will need to use PicoFlow Alpha's programming support to upload code to the microcontroller.

You can do this by pressing the big Program button at the top of the screen. Make sure that the right type of microcontroller is selected in the drop-down box; it should be set to "14 Digital 16F505" or "14 Analog 16F506". The Robot also needs to be powered up before programming. Make sure that



Screen 1: This is the simplest program you can use with the PicoKit. All it does is move the left wheel forward (C4 high). Make sure that on the Programming menu the value selected is "14 Digital 16F505" or "14 Analog 16F506".

all the leads are connected securely as intermittent connections can stall the programmer.

Note that the photodiode/IR LED modules can potentially interfere when programming, unplug them before you start programming.

If you're having trouble getting it to program correctly (freezes, fails or takes too long), try putting some pressure on the connection between the programmer and the board. We found that the 2.5mm jack plug didn't always make good contact with the socket and we had to hold it in to get the programming to work reliably.

You should see the LED on the programmer rapidly flash while it does its job, which takes a few seconds. If it's still going after 10 seconds, then something is wrong.

A more advanced program

Once you've gotten the Robot to move, you can move on to some more advanced programs that take advantage of the different features of the PicoPi Pro Robot.

Next, we'll write a program that writes to the LCD screen, drives both motors forward, stops, plays a small tune on the buzzer and then restarts the motors again and repeats.

First, we need a plain Start tool. Then, we create a Comms Tool (it looks like a serial port). Double-click on it and set it to transmit mode. Then go into the transmit sub-menu, set the source to literal, data-type to DEC (decimal) and value to 1.

Most importantly, the size needs to be set to 9 bits and make sure the output pin selected is B4 (the pin connecting the LCD screen).

That step clears the LCD screen before any text is written to it.

Next, we create another Comms Tool set to transmit, but this time we set the source to text and again the output pin is B4. Here, you can enter whatever message you want to display, up to 32 characters long. Next, we use a Delay Tool (hourglass). Again, by double-clicking it, you'll bring up a menu where you can set a time and units (from microseconds to years).

We chose two seconds for our delay. Next, you need to place a Digital Output Tool to control the motors. Set C3 and C4 high similarly to how we did it in the previous example. That should make the Robot drive forwards (assuming its motors are wired up with the correct polarity).

Add another Delay Tool (say about half a second), then use another Digital Output tool to bring those same two pins back to a low state.

Create a final Digital Output Tool and connect this to the Sound Tool. Once again, double-click the icon and then go to the music sub-menu. This uses musical notation to determine the sound played on the piezo buzzer using a square wave.

There are quite a few options you can fiddle around with if you are musically inclined, to create reasonably lengthy sequences of notes.

It accepts musicXML files, so you can find sheet music online and load it up in this software to replay on the buzzer. The sound tool is fairly powerful, but it would help to know how to read sheet music.

The Music Editor can be accessed by clicking on Edit Music within a Sound tool. You can put notes into by selecting them as shown above, or you can load a musicXML file found online.

More experimentation

This Robot sample program and several others are available as a free download from the SILICON CHIP website. Some of them take advantage of the infrared sensors on the front of the Robot to allow it to follow a black line.

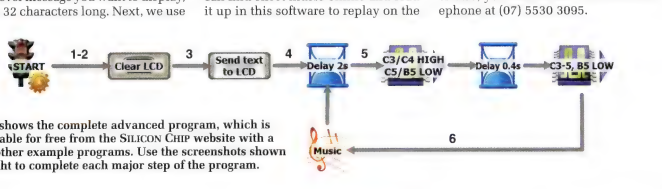
There's also a program that will move a motor depending on which of the two pushbutton switches are pressed.

You should be able to load each program, see how it works and start changing individual parts to see what does what. You can then start to modify your own, more advanced programs or even create them from scratch.

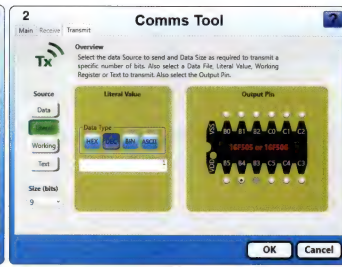
Where to buy it

The PicoPi Pro Robot kit is available for $110 from: **www.picokit.com.au/Store/index.php?route=product/product&path=2&product_id=122**

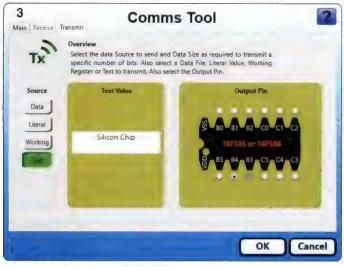
You will need to make an account to view prices and make orders. Otherwise, you can contact them via telephone at (07) 5530 3095.



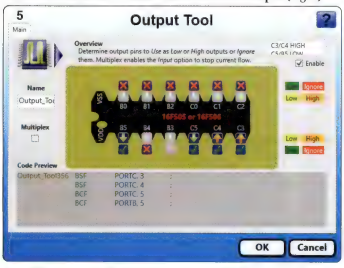
This shows the complete advanced program, which is available for free from the SILICON CHIP website with a few other example programs. Use the screenshots shown at right to complete each major step of the program.

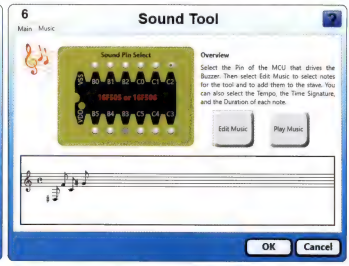


Connect the Start tool to the input of a Comms Tool, double click the Comms Tool and set it to transmit (left). Then in its transmit submenu (right) the source should be set to literal, data type to DEC with a value of 1 and its size to 9 bits. The output pin is then set to B4 of the micro.



A second Comms Tool (left) is linked to the output of the previous Comms Tool and also set to transmit, but the source is set to Text. You can then enter whatever 32 letter long message you want to display and set the output pin to B4. A Delay Tool of two seconds is then connected to its output (right).





A Digital Output Tool (left) is connected to the output of the previous Delay Tool, which brings pins C3 & C4 high, driving both wheels forward. This is connected to a 0.4s Delay Tool before going to another Digital Output Tool which brings these same pins C3 & C4 low again. After which it connects to a Sound Tool which outputs a small tune to the piezo buzzer, this Sound tool is then connected to the first two second Delay Tool to form an endless loop. SC

CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

Using a stepper motor for star tracking with a telescope

I wanted to modify an old Celestron telescope, which had an equatorial drive motor driven by 230VAC. This required a nearby mains supply or a battery powered inverter. To make it easier to use, I modified it to run from a 12V battery to make it completely portable.

There are two version of this telescope, one uses two synchronous motors 180° apart, while the one I have uses a single motor. The former can likely be modified to work with this circuit.

Both require a final drive speed of 15 RPH (1/4 RPM) in order to get one revolution every 24 hours. This allows the telescope to be used in equatorial alignment to track celestial objects.

I considered using a stepper motor to drive the final gear directly, but I would have needed a fairly large motor to provide the necessary torque and the individual steps might have introduced vibration.

Stepper motors are precise in their motion but limited in their maximum speed and require the same current whether stationary or moving.

I first attempted to use the original gearbox with a smaller stepper motor and a universal joint but the motor could not rotate fast enough to provide the final rotational speed.

I then came across a series of small stepper motors with inbuilt reduction gearboxes, typically used in robotics. The model code is 28BYJ-48 and they cost less than $5 each. They are specified as 32 steps per turn with a reduction gear ratio of 63.84:1.

This is not ideal as it means that one full rotation of the output shaft requires 2042.88 steps (not a whole number!) but I decided I could figure out a way to get the required output shaft rotation rate.

I decided to use a quartz crystal oscillator as the timebase for stability. A 32,768Hz crystal seemed the simplest option. I would need to divide this down to get an 8.509Hz signal for the stepper motor.

This gives 240 seconds per rotation of the motor's output (8.509 ÷ 32 ÷ 63.84), which is equal to the desired 15 revolutions per hour.

So that is the purpose of this circuit, to provide the 8.509Hz drive to the stepper motor from a 12V battery power source.

X1 is the reference crystal and it is driven by IC1c, one of the four gates in a 4093B quad 2-input NAND schmitt trigger IC. In this circuit, all four gates have their inputs joined, effectively making it a quad inverter.

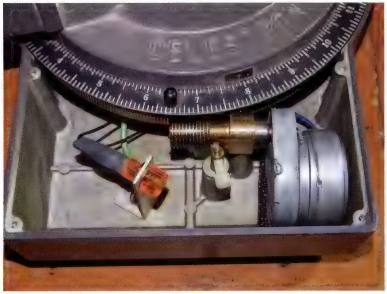
The crystal is connected across that inverter stage with two load capacitors and a 10MΩ resistor to provide start-up current. The 32,768Hz signal appears at its output, pin 10.

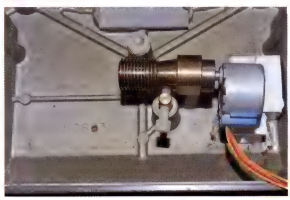
This is squared up by another inverter stage, IC1d, then fed to the clock input of binary divider IC2 via toggle switch S1. IC2 divides its frequency down by a range of different power-of-two values.

The O0 output (pin 9) toggles after each pulse on pin 10, the O3 output (pin 7) toggles after 8 pulses and so on, up to O13 which divides the frequency by 16,384, resulting in a 2Hz output.

But we need a strange division ratio of around 3851 (32,768 ÷ 3851 = 8.509). We can get a frequency close to this by combining the O4, O9, O10, O11 and O12 outputs using diodes D1-D5. Their common anode pins are connected to an 18kΩ pull-up resistor, so the anodes will only go high when all five of those output pins go high.

This happens after 3848 pulses ($2^{11} + 2^{10} + 2^9 + 2^8 + 2^3$). That gives a frequency of 8.516Hz (32768 ÷ 3848),





Left: the old 230VAC tracking motor used to turn the worm gear which adjusts right ascension (RA). Below: the new 5V DC 28BYJ-48 4-phase, 5-wire stepper motor attached to the worm. It is driven by a ULN2003A Darlington array IC. These stepper motors are also available with a driver board included.

which is only off by 0.1%. After 3848 pulses, the Master Reset pin (pin 11) of IC2 goes high, resetting all the outputs back to the low state.

So output O12 of IC2 generates a signal with a frequency of 8.516Hz and duty cycle a little below 50%. That signal is then fed to the clock input (pin 14) of decade counter IC3. Its O4 output pin is connected directly to its master reset input, so it resets itself every four pulses.

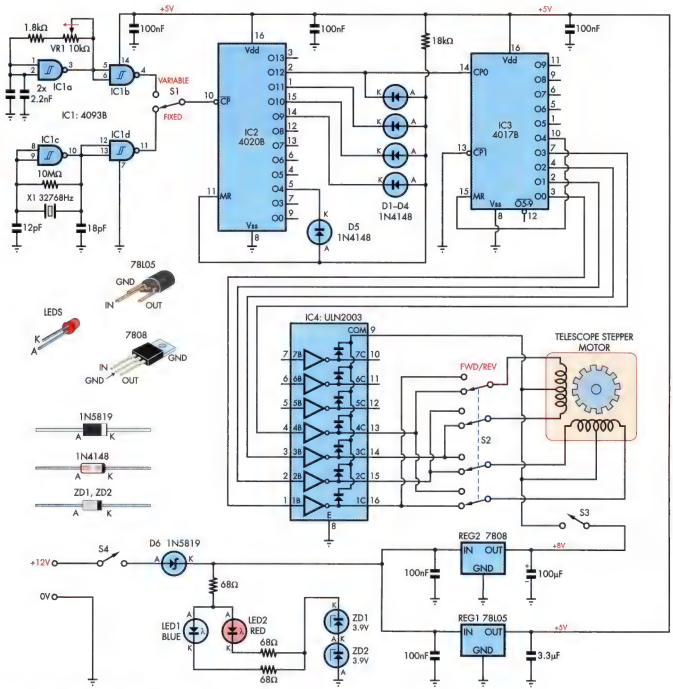
The output pins O0-O3 of IC3 go high in turn on each pulse from IC2, which provides the stepper motor coil sequencing.

Each of these outputs drives one input of IC4, a ULN2003 Darlington array, which acts as a buffer to provide the current required to drive the relay coils when the outputs of IC3 go high.

It drives the tapped stepper motor coils via 4PDT switch S2, which allows the motor rotation to be reversed so that the unit can be used in either the northern or southern hemisphere.

We've skipped over the purpose of inverter gates IC1a and IC1b at upper left. These provide an alternative clock source for the whole system, using a free-running oscillator controlled by potentiometer VR1 rather than the crystal, in case you want to set the motor to run at a different speed. The clock source is selected by switch S1.

The variable oscillator can provide speeds between about half and three times that of the fixed oscillator.



TELESCOPE MOTOR DRIVER

Power supply

Power from the 12V battery is switched using S4 while schottky diode D6 provides reverse polarity protection. This is regulated to 8V by REG2, to provide the stepper motor supply.

The stepper motor power can be disconnected using switch S3. The motor is designed to run from 5V but this type has been used successfully by others with a 12V supply, so an 8V supply works OK.

REG1 derives the 5V rail to power IC1, IC2 and IC3.

Red and blue LEDs are connected across the 12V supply with resistors and zener diodes in series, both to indicate when power is applied and to act as a low battery warning. Red LED2 remains lit well below 9V while blue LED1 will gradually fade and extinguish at about 9.5V.

The circuit draws about 400mA in use unless the motor is switched off. With a 5Ah battery, you can expect more than 10 hours of use after a full charge.

Assembly

For normal use, the telescope will be mounted with the forks pointing towards the South Celestial Pole. The wedge plate will then be on the north side of the tripod. There is a bubble level on the wedge to ensure the base is horizontal.

The telescope is mounted by placing a mounting screw in the telescope base, furthest from the control panel. The telescope is then lifted onto the wedge, allowing this screw to fall into the slot cut at the top of the wedge. Tightening the screw is usually sufficient to hold the telescope firmly in place but there are two other bolt holes on the telescope and the wedge.

It is advisable to plug the power cable into the drive before doing this as there is limited space once the telescope is mounted.

Right ascension (RA) can be changed by loosening the RA clamp (rotate anti-clockwise). Some fine adjustment is possible by loosely tightening the clamp and turning the knob. This is not particularly smooth. Once in place tighten the clamp by turning it fully clockwise.

Note that the final worm drive is held in place by an adjustment screw and spring. If excessive force is applied, the worm may lift off the drive and you will hear it slipping over the circular gear.

Declination is adjusted by loosening the clamp on the forks; This is loosened by rotating it forward in line with the telescope tube. Fine adjustment can be made at any time with the adjustment screw on the forks.

This has limited movement. If it becomes difficult to turn, reset it to its centre point, loosen the clamp and then rotate the main tube.

Once the desired object has been found, switching on the main drive in normal mode should hold it in view. Errors in mounting the telescope may lead to a need to adjust the declination screw occasionally.

In right ascension, adjustments may be made by:

1. turning off power to the motor;
2. reversing the motor. There is a small amount of backlash in doing this, which causes a small jump in the position;
3. changing to variable speed drive; this has the potential to give the finest adjustment.

Graham Jackman, Melbourne, Vic. ($100)

Switchable AC voltage source with unregulated DC supply

This device is relatively easy to build and doesn't require a custom PCB but it's also quite useful, especially when testing security equipment (CCTV cameras etc) which are often powered from low voltage AC.

I used to use a bare transformer for this sort of testing but now that I am about to have grandchildren running around, I need something that isn't a shock hazard.

This box can deliver 9, 12, 15, 18, 24 or 30VAC at up to 2A at the touch of a switch. This is achieved using a multi-tapped transformer (Jaycar MM2005) with its secondaries switched by six 12V relays with a minimum contact rating of 2A, to match the transformer.

Rotary switch S2 applies power to the coil of one of the relays, which connects the appropriate secondary to the output terminals.

For the voltages where a centre tap is available (18, 24 and 30VAC), the other pole of the relay (RLY4-RLY6) is used to connect that tap to a third output terminal.

It's best to use a break-before-make (BBM) rotary switch to avoid shorting out the secondaries when switching, but given that such a short would be brief (10-20ms), it isn't going to cause any damage.

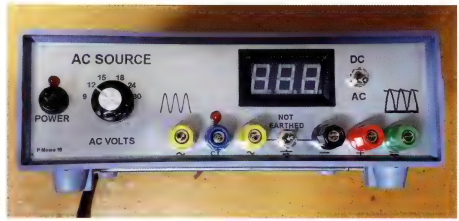
The second set of contacts of RLY1-RLY3 are connected so that LED2 lights up when a centre tap connection is available. This LED is physically located immediately above the centre tap binding post.

It works because RLY1, RLY2 and RLY3 are all de-energised if one of relays RLY4-RLY6 are energised, and in this state, current can flow from the positive terminal of BR1, through RLY1, RLY2 and RLY3 and then to LED2. If any of RLY1-RLY3 are energised then this connection is broken and LED2 switches off.

BR1 provides a ~12V DC supply to power the relay coils, from a small secondary transformer. This supply is also used to light LED2 and power-on indicator LED1. It also feeds 5V linear regulator REG1 which provide a 5V supply to the LED panel meter which displays the current output voltage.

For convenience, the AC output is also rectified by bridge rectifier BR2 and made available at a pair of binding posts marked + and -.

This rectified voltage is also filtered by a 2200µF capacitor (isolated via diode D1) and so an unregulated DC supply is available on the DC binding post.



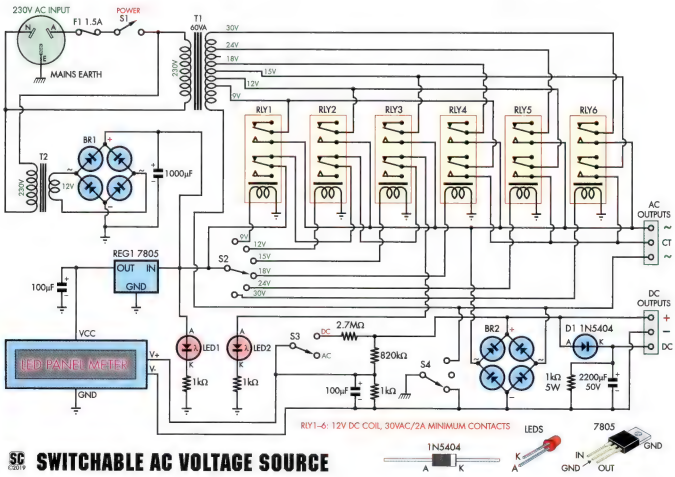
This switchable AC voltage source can deliver up to 30VAC at 2A from mains power. Since the AC output is also rectified and filtered, an unregulated DC supply is available on the DC binding post.

Switch S4 allows either one end of the AC output or the DC negative terminal to be Earthed, or neither, for when you need a floating supply. Switch S3 changes the scaling for the panel meter so that you get an approximate reading of either the AC or DC output voltage depending on its position.

The scaling is designed to suit a 200mV full-scale meter. A 100µF capacitor provides some filtering to give a relatively steady voltage display.

The connections as shown suit a meter with four wires, ie, separate positive and negative sensing inputs. If you have a 3-wire meter, connect the negative sense wire to panel ground.

Peter Moore,
Camberwell, Vic. ($60)



SWITCHABLE AC VOLTAGE SOURCE

Using a touch-tone telephone to send coded radio signals

I needed a way to wirelessly send one of several control signals to a robot I was working on.

I had some spare touch-tone telephones lying around (remember those?) so I decided to use one to generate DTMF control signals, then transmit the resulting audio signal over FM. A standard FM receiver and DTMF decoder can then be used to receive and decode the signals on the robot, triggering certain actions.

The circuit is powered from a 12V DC supply, with diode D1 for reverse polarity protection and the 470µF and 10nF capacitors provide some filtering. This is then used to light power indicator LED1 and to power the telephone. The telephone would usually be connected to a balanced line but in this application, it works fine in unbalanced mode.

The telephone current is limited by a 270Ω 1W resistor and the audio/DTMF tones appear across this resistor. It provides sufficient current for the phone to operate. The audio signal from the top end of that resistor is then AC-coupled to volume control potentiometer VR1, which forms an adjustable voltage divider in conjunction with a 1kΩ fixed resistor.

The attenuated audio signal is again AC-coupled, this time to the base of transistor Q1, with a 1nF capacitor to ground filtering out any RF which may have been picked up in the input wiring. Q1 is wired as an FM oscillator, with its frequency adjustable via trimcap VC1. The audio fed to its base modulates the oscillator output.

This is coupled via air-cored transformer L1/L2 to the base of Q2, a buffer transistor, which has fixed bias via the 3.3kΩ and 5.6kΩ resistors at the other end of L2. It isolates the oscillator from the antenna, minimising the aerial loading on Q1 and so reducing frequency drift from any changes in the aerial (eg, a change in length, a hand brought near it etc).

The aerial is a telescopic type with the ideal length being a quarter wavelength of the selected transmission frequency. Q2's emitter resistor, trimpot VR2, allows the output power to be adjusted into the permissible range (which is 10µW for unlicensed FM broadcast band transmitters in Australia).

If you don't have an RF power meter, a properly tuned quarter-wave whip antenna typically has an impedance of around 36.8Ω. So to get 10µW output, we can calculate that you need to adjust VR2 to get 19mV RMS at the antenna.

But note that you would need test equipment which could measure voltages at FM broadcast band frequencies and also keep in mind that loading from the test equipment could affect the output amplitude.

It may be easier to measure the RMS voltage at the emitter of Q2 relative to ground and then calculate how to adjust VR1 to get the required 19mV at the antenna.

To set up the FM transmitter, extend the antenna, switch on an FM radio, set it to the desired frequency (an unused spot on the FM band) and place

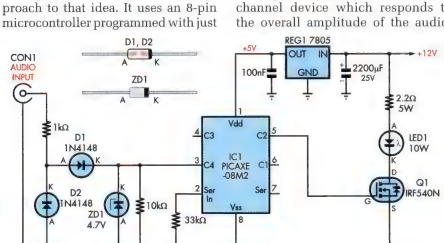
Flashing LEDs in time to music

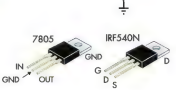
This circuit is inspired by the various "Musicolour" projects published in *Electronics Australia* and then later in SILICON CHIP. The latest of these was published in the October and November 2012 issues (siliconchip.com.au/Series/19). These all have one thing in common: they flash or vary the brightness of several coloured lights in time to music.

This circuit is a minimalist approach to that idea. It uses an 8-pin microcontroller programmed with just 22 bytes of code to drive one LED with a pulse-width modulated signal that has a duty cycle proportional to the amplitude of the music signal.

I decided to use a PICAXE08M microcontroller since I already had one and they are easy to program. They also include the requisite analog-to-digital converter (ADC) and pulse-width modulation (PWM) hardware features.

I'm presenting it here as a single-channel device which responds to the overall amplitude of the audio.





SC ©2018 **MUSIC ACTUATED LED FLASHER**

But since the circuit is so simple and cheap, you could build several and then connect various bandpass filters in front of each, so that each light responds to a different portion of the audio spectrum. That is typically how Musicolours of the past worked.

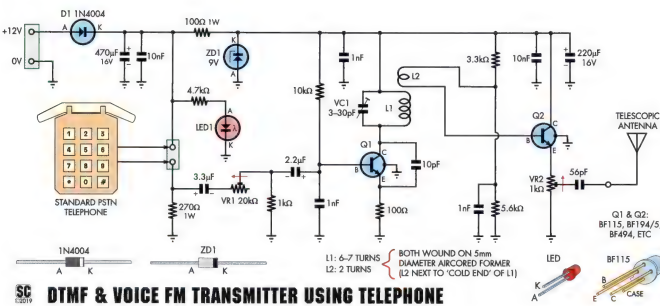
You could also build one (or a set) for each channel, ie, left and right of a stereo recording.

The audio signal is fed in via CON1 and rectified by diodes D1 and D2, with a 1kΩ series resistor preventing the loading from these diodes from affecting the audio signal too badly. It may be fed elsewhere, such as to an audio amplifier, so we don't want to distort it. A 10kΩ loading resistor ensures that the rectified signal is clean.

This rectified signal is then fed into input/output C4 (pin 3) of IC1, which is configured by the software as an analog input. Zener diode ZD1 prevents the voltage on this pin from exceeding 5V.

IC1's input/output C2 (pin 5) is configured as a PWM digital output and this is connected directly to the gate of N-channel Mosfet Q1 so that when pin 5 goes high, the Mosfet switches on and thus current flows through LED1.

LED1 is a 10W device, which internally is several smaller LEDs in a series/parallel arrangement, giving



DTMF & VOICE FM TRANSMITTER USING TELEPHONE

it a few metres from the transmitter, but not so far that you can't hear it.

Adjust VC1 to get minimum noise from the radio (ie, maximum quieting) and then adjust VR1 for minimum distortion while transmitting voice and/or DTMF signals.

You can verify that the output power is not excessive by checking how far away you can pick the signal up with an FM radio. With the legal 10µW transmission power, it should start to break up around 10m from the transmitter (plus or minus a bit, depending on the quality of the radio being used as the receiver).

Note that the circuit board and attached leads form a pseudo ground plane for RF signal propagation. When building the circuit, keep in mind RF best practices such as keeping the whole thing rigid and the wiring short.

Other audio sources could potentially be fed to the circuit in place of the telephone signal.

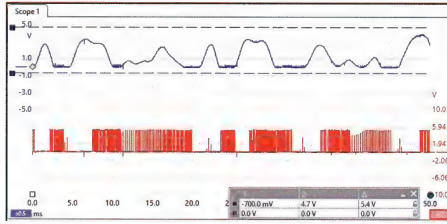
Warwick Talbot,
Toowoomba, Qld. ($65)

a forward voltage of around 9-10V. Therefore, a 12V DC power supply is used, with a 2.2Ω 5W current-limiting resistor to set the LED current to around 1A. A 2200µF electrolytic capacitor is used to smooth the 12V rail while a 7805 regulator provides the 5V supply for IC1.

The code for IC1 is very simple:

```
'8 bit variable to store ADC data
symbol adc_level = b0
'16 bit variable for duty cycle
symbol pwm_duty = w0
init:
  'Set clock frequency to 8MHz
  setfreq m8
  'Set LEDs off initially
  low 2
main:
Do
  'Use 8 bit ADC read
  Readadc 4, adc_level
  'Convert 256 levels to 1024
  let pwm_duty = adc_level*4+3
  'Output PWM
  Pwmout 2, 255, pwm_duty
Loop
```

A scope capture of the running circuit is shown here. You can see how the PWM duty cycle (red) varies in response to the rectified audio signal (blue). Note that there is some delay between the input signal changing and the duty cycle being updated.



This scope capture shows the rectified audio signal (blue) and the PWM signal (red). You can see how the PWM signal duty cycle increases a short time after the audio signal amplitude increases.

The 10W LEDs I used cost about $1 each on eBay and are available in different colours including red, green and blue. They need to be attached to a suitably large heatsink. Q1 should not need a heatsink.

I built three copies of this circuit, using three differently coloured LEDs and then fed the audio signal to them via three Multi-Function Active Filter modules that I built from a Jaycar kit, based on the SILICON CHIP article from July 2009 (**siliconchip.com.au/Article/1505**). I set up each filter so that the LED would respond to audio over a different frequency range.

Use a PICAXE USB programming cable to upload the code to the chip(s). You will need a board with a socket for the chip and a jack socket to make the connection to the programmer – see the PICAXE literature for details on how to program the chip; besides the sockets, you just need two resistors.

Nigel Quayle,
Smithfield, Qld. ($55)

VINTAGE RADIO

By Associate Professor Graham Parslow

1958 Stromberg-Carlson Baby Grand 48A11

The Baby Grand epitomises simplicity; it is a minimalistic radio, stripped back to the bare essentials, yet still quite handsome. It is a conventional 4-valve, mains-powered MW superhet.

The name "Baby Grand" is an odd choice for such a plain radio. I suspect that someone laughed when they adopted that name.

Despite their simplicity, these radios perform as well as, if not better than, contemporary five-valve radios. Put it this way: they sound as good as is possible for a radio with a five-inch general-purpose speaker.

Few other radios have such minimalist styling. At the time this radio was designed, the Brutalist Movement in architecture was at its peak, featuring plain buildings that were functional and lacking intricate adornments – perhaps inspired by the similarly brutal military structures of WW2, which would have been fresh on the memories of the architects in the early 50s.

The Brutalist movement flourished from the 1950s through to the 1970s and is strongly linked to the architect Le Corbusier. You will probably have seen public buildings and high rises that illustrate that period of austere design. Sydney's MLC Centre in Martin Place and the UTS Tower at Broadway are good examples, as are the Victorian Arts Centre and Hamer Hall on the Yarra in Melbourne.

That might give you some idea of the radio's aesthetic inspiration.

Despite having just three RF/audio valves, the radio sounds good because the speaker is firmly screwed to the front panel, so it is better baffled than many other contemporary radios.

Design details

As the photos show, the enclosure is a simple timber box with rebated cleats into which the chassis slides.

The chassis is also minimalist in that it is a single steel sheet with two folds. This creates flanges that slide into the slots. In creating this simple chassis, Stromberg-Carlson was emulating the budget strategies of their competitors, keeping the cost low.

The tuning knob has stations marked on the side. The same scheme was used on the Stromberg-Carlson model 79TII transistor radio from 1959. On the Baby Grand, the knobs are on the side while the transistor radio has the calibrated knobs on the top. In both cases, the station markings are visible from the front of the radio.

There were four different sets of station markings used on the radio, each accommodating two Australian states. Cleverly, the knob is moulded with two flats in the spindle hole so it can slide onto the tuning shaft in either of two orientations, rotated by 180°. This allows the stations to be visible for one state or the other.

For example, with the radios shown here, the station marker stud (set into the case) indicates either Victorian stations or, in the alternative mounting position, NSW stations.

Radios from other major manufacturers at the time also commonly used

a direct drive from the tuning knob to the tuning capacitor.

However, the others used a face-mounted circular Perspex dial with a cursor that moved over stations displayed behind the knob. The Stromberg-Carlson approach has the dual advantages of needing fewer components and reserving the whole face of the radio for the speaker grille.

The two-gang tuning capacitor and the IF coils are all of conventional size. Other manufacturers, notably Philips, were starting to use smaller components in valve radios at this time. This was the dawn of commercially viable transistor radios and the need for lightweight, compact components drove miniaturisation.

The contemporary Stromberg-Carlson model 79TII transistor radio mentioned earlier used a miniature tuning gang and other lightweight components, so it weighed just 2.4kg. Even with standard components, the Baby Grand still weighs in at a relatively light 3.1kg.

This was the era of families saving to buy their first TV and so the family radio budget was not high. Before the second world war, Stromberg-Carlson made only high-end radios but afterwards, they had mixed offerings through a wide price range.

Circuit details

In 1958, valve radios had reached a peak of evolution using efficient miniature valves and associated circuitry. This radio features only one surprise for its time: the use of an OA79 germanium diode as the detector and AGC generator.

The circuit is shown in Fig.1. Reception starts with a large ferrite rod antenna. There is also a coupled external aerial winding, allowing signal strength to be increased if necessary. This is not shown on the circuit diagram but can be seen in pictures of the radio. The external aerial wire simply dangles from one of the ventilation holes in the back panel.

The mixer-oscillator in this superhet circuit is a 6BE6. The 6BE6 was registered by RCA at the end of 1945 and proved to be a reliable design. A tap on the oscillator coil is connected to the cathode of the 6BE6 to provide positive feedback and maintain stable performance of the local oscillator. This type of oscillator circuit was devised by Ralph Hartley in 1915 and is named after him.

The other 6BE6 connections are all standard, with the broadcast signal applied to the control grid and the anode feeding the 455kHz heterodyne signal to the first IF transformer. The negative control voltage for AGC is supplied to the 6BE6 grid, derived from the anode of the OA79 diode (the cathode of the diode connects to Earth).

The main circuit diagram simplifies the internal electrode arrangement of the pentagrid 6BE6. All 7 pins of this miniature valve have functional connections.

The first IF transformer feeds very simply into the grid of a 6BA6 7-pin pentode. The 6BA6 was designed to amplify RF signals and is another reliable design from RCA America, first registered in October 1945. Like the preceding stage, the negative control voltage for AGC is supplied to the 6BA6 grid from the anode of the OA79 diode.

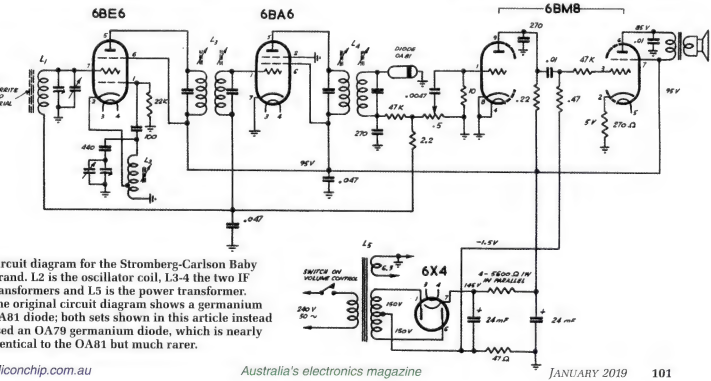
Thanks to the OA79 germanium diode, the set does not need a diode/triode valve. It instead has a 6BM8 incorporating a triode audio preamplifier and an output pentode, combined in the same glass envelope. The circuit diagram again simplifies the electrode complement of the pentode.

The triode section has a claimed amplification factor of 70. Accordingly, this valve was commonly used in record players with crystal pickups, where high amplification was required. Valve data indicates that a 300mV input can result in 3W of audio output with the anode at 260V. Philips registered the valve in 1956 with the European designation ECL82.

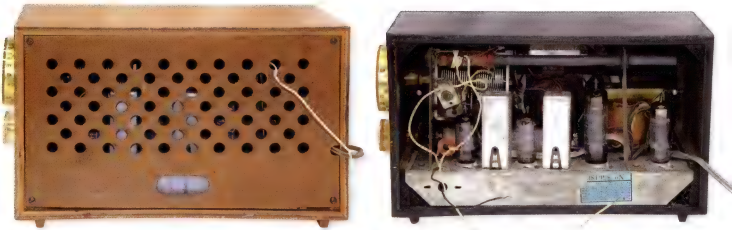
Entry level guitar amplifiers were another typical application for the 6BM8.

The circuit diagram shows the pentode plate at 85V. At first glance, it might seem that the triode plate is at 270V, but that is actually the value of the plate decoupling mica capacitor of 270pF.

HT voltage of just 85V seems improbably low, but a high impedance



Circuit diagram for the Stromberg-Carlson Baby Grand. L2 is the oscillator coil, L3-4 the two IF transformers and L5 is the power transformer. The original circuit diagram shows a germanium OA81 diode; both sets shown in this article instead used an OA79 germanium diode, which is nearly identical to the OA81 but much rarer.



The back of the set with the external aerial wire and mains power cable hanging out. Apart from the colour of the cabinet, logo and power cable, there isn't any other difference between these two sets.

voltmeter confirmed the printed value. I measured a 140V output from the HT rectifier, 90V from second electrolytic filter capacitor, 86V at the 6BM8 pentode plate (circuit shows 85V) and 40V at the 6BM8 triode plate (after replacing the series 220kΩ resistor, as described later).

The benefit of these low high-tension values is a meagre power consumption of just 24W, while still delivering a satisfactory volume level.

Electrical restoration

This radio is among the easiest valve radios to work on because most components are mounted on a tag board with a logical layout and good accessibility. The low component count is also reflected in the chassis view from the top showing, a relatively uncluttered layout.

As shown in the photos, I purchased two of these radios, one in a black case and one in a stained timber case.

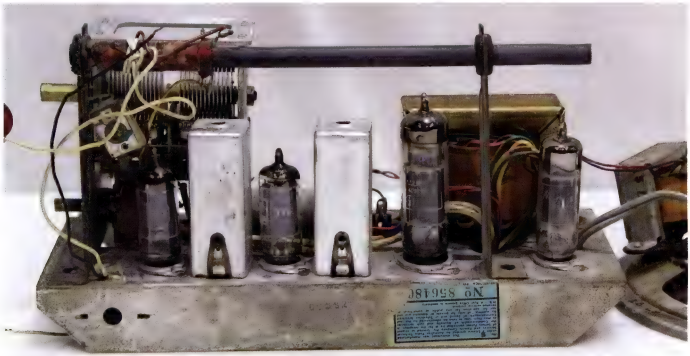
The black-case radio worked well from power up. But the timber veneer radio crackled. Even with the volume control set at zero, it still made the irritating noise, so the crackle was clearly being produced after the volume control pot. I progressively replaced the most likely components that could generate crackle.

Changing the HT filter electrolytics made no difference. A replacement 6BM8 made no difference. Shorting either grid in the 6BM8 to Earth eliminated the crackle. I could not find any dry joints, despite much prodding and pulling. I then replaced all the paper capacitors in the audio circuitry but still, there was crackle.

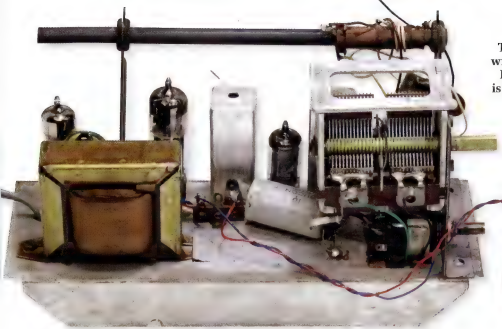
At least there was one useful outcome of all these replacements. The coupling capacitor to the pentode grid was leaky and upon changing it, the pentode grid bias went from -3.2V to -5.0V.

The original 220kΩ resistor to the triode plate measured high at 324kΩ but replacing it didn't solve my problem. Replacing the 10MΩ 6BM8 triode grid-to-Earth resistor also did nothing.

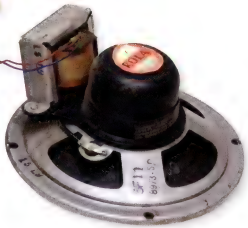
It was time to be more systematic. A signal tracer found no crackle at the triode grid, but crackle was audible



A closer view of the chassis from the rear, out of its case. From left to right, the valves are: 6BE6, 6BA6, 6BM8, 6X4.



The front of the Baby Grand chassis with a Rola 5-inch 3.5Ω loudspeaker. Like other radios, the power switch is integrated with the volume control pot, visible near the bottom of the chassis.



at the triode plate. The only component that I had not replaced that connected to the triode plate (pin 9) was the 270pF mica capacitor that was designed to shunt any high-frequency signal to Earth.

Sherlock Holmes asserted that when every other explanation has been eliminated, then the only one remaining must be the truth. Indeed, Holmes proved correct. Replacing the mica capacitor to the 6BM8 triode plate killed the crackle.

In sharing this experience with others, I discovered what is now becoming ever more common in vintage radios. mica capacitors look rugged and indestructible, but they are now reaching an age where their failure leads to crackle. If you encounter a case of crackle, start by replacing the mica capacitors.

All that remained was to fire up the signal generator and slightly improve the performance by aligning the set.

The photos show the original two-core figure-8 mains leads. I replaced these with 3-core cable, Earthed to the chassis.

Case restoration

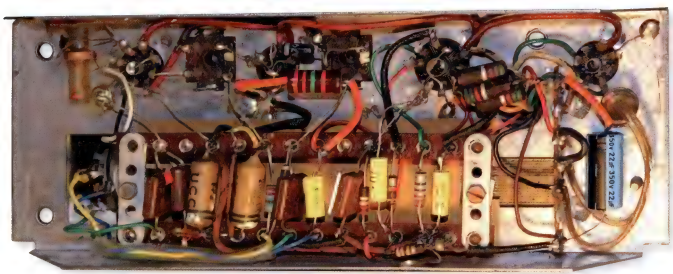
When I bought it, the black-case radio had damage on the edges of its case, exposing bare timber. The fascia is held in by plastic lugs penetrating through the woodwork of the front of the case. The black case was separated from the facia and resprayed with satin black to provide the much-improved appearance seen in the photos.

The timber veneer case was likewise abraded at the edges and so I refinished it with satin polyurethane.

A fellow member of the Historical Radio Society of Australia told me that he originally thought these Baby Grand radios were ugly, but he is now changing his mind.

Beauty is in the eye of the beholder and these radios make a statement that is alternative to other mainstream radios of the time. Sometimes less is more, as the aphorism suggests.

Sadly, these innovative sets did not save the company from other forces in play at the time. Stromberg-Carlson tried to participate in the Australian television market, but they were not competitive and all manufacture ceased in 1961. SC



The underside of the restored chassis. The source of the crackle was due to a single mica capacitor, located between two of the replacement MKT capacitors (marked by the white line).

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✔ **PHONE** (9am-5pm AET, Mon-Fri): Call (02) 9939 3295 (INT +612 9939 3295) – have your order ready, including contact and payment details!

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PRE-PROGRAMMED MICROS

Micros cost from $10.00 to $20.00 each + $10 p&p per order#

$10 MICROS

ATtiny816	**ATtiny816 Development/Breakout Board (Jun19)**
PIC12F617-I/P	Temperature Switch Mk2 (June18), Recurring Event Reminder (Jul18) Door Alarm (Aug18), Steam Whistle (Sept18) White Noise Source / Tinnitus & Insomnia Killer (Sept18 / Nov18)
PIC12F675-I/P	UHF Remote Switch (Jan09), Ultrasonic Cleaner (Aug10) Ultrasonic Anti-fouling (Sep10), Cricket/Frog (Jun12), Do Not Disturb (May13) IR-to-UHF Converter (Jul13), UHF-to-IR Converter (Jul13) PC Birdies "2 chips – $15 pair" (Aug13), Driveway Monitor Receiver (July15) Hotel Safe Alarm (Jun16), 50A Battery Charger Controller (Nov16) Kelvin the Cricket (Oct17), Triac-based Mains Motor Speed Controller (Mar18) Heater Controller (Apr18), Useless Box IC3 (Dec18)
PIC12F675-E/P	Courtesy LED Light Delay for Cars (Oct14), Fan Speed Controller (Jan18)
PIC16F1455-I/P	Microbridge (May17), USB Flexitimer (June18), Digital Interface Module (Nov18)
PIC16F88-E/P	Hi Energy Ignition (Nov/Dec12), Speedo Corrector (Sept13), Auto Headlight Controller (Oct13), 10A 230V Motor Speed Controller (Feb14) Automotive Sensor Modifier (Dec16)
PIC16F88-I/P	Projector Speed (Apr11), Vox (Jun11), Ultrasonic Water Tank Level (Sep11) Quizzical (Oct11), Ultra LD Preamp (Nov11), 10-Channel Remote Control Receiver (Jun13), Revised 10-Channel Remote Control Receiver (Jul13) Nicad/NiMH Burp Charger (Mar14), Remote Mains Timer (Nov14) Driveway Monitor Transmitter (July15), Fingerprint Scanner (Nov15) MPPT Lighting Charge Controller (Feb16), 50/60Hz Turntable Driver (May16) Cyclic Pump Timer (Sep16), 60V 40A DC Motor Speed Controller (Jan17) Pool Lap Counter (Mar17), Rapidbrake (Jul17), Deluxe Frequency Switch (May18) Useless Box IC1 (Dec18)
PIC16LF88-I/P	Garbage Reminder (Jan13), Bellbird (Dec13), GPS Analog Clock Driver (Feb17)

$15 MICROS

PIC16F1459-I/SO	Four-Channel DC Fan & Pump Controller (Dec18)
PIC16F84A-20/P	Programmable Ignition Timing Module (Jun99), Fuel Mixture Display (Sept00) Oscar Naughts And Crosses (Oct07), UV Lightbox Timer (Nov07)
PIC16F877A-I/P	6-Digit GPS Clock (May-Jun09), 16-bit Digital Pot (Jul10), Semtest (Feb-May12)
PIC16F2550-I/SP	Batt Capacity Meter (Jun09); Intelligent Fan Controller (Jun10)
PIC16F450B-I/P	Multi-Purpose Car Scrolling Display (Dec08), GPS Car Computer (Jan10)
PIC32MM0256GPM028-I/SS	Super Digital Sound Effects (Aug18)
PIC32MX170F256B-50I/SP	GPS Tracker (Nov13), Micromite ASCII Video Terminal (Jul14) Micromite Mk2 (Jan15) + *47µF*, Low Frequency Distortion Analyser (Apr15) Micromite LCD BackPack (either version) (Feb16), GPS Boat Computer (Apr16) Micromite Super Clock (Jul16), Touchscreen Voltage/Current Ref (Oct-Dec16) Micromite LCD BackPack V2 (May17), Deluxe eFuse (Aug17) Micromite DDS for IF Alignment (Sept17), Tariff Clock (Jul18) GPS-Synched Frequency Reference (Nov18)
PIC32MX795F512H-80I/PT	Maximite (Mar11), miniMaximite (Nov11), Colour Maximite (Sept/Oct12) Touchscreen Audio Recorder (Jun/Jul 14)
dsPIC33FJ64MC802-E/SP	Induction Motor Speed Controller (revised) (Aug13)

$20 MICROS

PIC32MX470F512H-I/PT	Stereo Audio Delay/DSP (Nov13), Stereo Echo/Reverb (Feb 14) Digital Effects Unit (Oct14)
PIC32MX470F512H-120/PT	Micromite PLUS Explore 64 (Aug 16), Micromite Plus LCD BackPack (Nov16)
PIC32MX470F512L-120/PT	Micromite PLUS Explore 100 (Sep-Oct16)
dsPIC33FJ128GP802-I/SP	Digital Audio Signal Generator (Mar-May10), Digital Lighting Cont. (Oct-Dec10) SportSync (May11), Digital Audio Delay (Dec11), Quizzical (Oct11), Ultra-LD Preamp (Nov11), LED Musicolor (Nov12)

When ordering, be sure to select BOTH the micro required AND the project for which it must be programmed.

SPECIALISED COMPONENTS, HARD-TO-GET BITS, ETC

P&P – $10 Per order#

LED CHRISTMAS TREE COMPLETE KIT (CAT SC4749) *(NOV'19)*
PCB and all on-board parts, discounted if buying in bulk. Provided with three high-brightness green, red and white LEDs. Extra 220Ω and 820Ω are included to better match the red and white LEDs respectively.
1 @ $10.00 – 4 @ $32.00 – 18 @ $126.00 – 31 @ $199.00 – 38 @ $229.00

DIGITAL INTERFACE MODULE KIT (CAT SC4750) *(NOV'18)* **$15.00**
Includes PCB, programmed micro and all other required onboard components

TINNITUS/INSOMNIA KILLER HARD-TO-GET PARTS (CAT SC4792) *(NOV'18)* **$10.00**
One LF505V regulator (TO-220) and LM4865MX audio amplifier IC (SOIC-8)

GPS-SYNCHED FREQUENCY REFERENCE SMD PARTS (CAT SC4762) *(NOV'18)* **$80.00**
Includes PCB and all SMD parts required

STEAM WHISTLE / DIESEL HORN KIT (CAT SC4696) *(SEPT'18)* **$15.00**
Set of two programmed PIC12F617-I/P micros

SUPER DIGITAL SOUND EFFECTS KIT (CAT SC4658) *(AUG'18)* **$40.00**
PCB and all onboard parts (including optional ones) but no SD card, cell or battery holder

RECURRING EVENT REMINDER PCB+PIC BUNDLE (CAT SC4641) *(JUL'18)* **$15.00**
PCB and programmed micro for a discounted price

USB PORT PROTECTOR COMPLETE KIT (CAT SC4574) *(MAY'18)* **$15.00**
All parts including the PCB and a length of clear heatshrink tubing

AM RADIO TRANSMITTER (CAT SC4533) *(MAR'18)* **$2.50**
MC1496P double-balanced mixer IC (DIP-14)

VINTAGE TV A/V MODULATOR *(MAR'18)*
MC1377P A/V modulator IC (DIP-14) (Cat SC4543) **$5.00**
SBK-71K coil former pack **(two required)** (Cat SC2746) **$5.00 ea.**

PARTS FOR THE 6GHz+ TOUCHSCREEN FREQUENCY COUNTER *(OCT'17)*
Explore 100 kit (Cat SC3834: no LCD included) **$69.90**
one ERA-2SM+ & one ADCH-80A+ (Cat SC3116?; two packs required) **$15.00/pk.**

MICROBRIDGE COMPLETE KIT (CAT SC4264) *(MAY'17)*
PCB plus all on-board parts including programmed microcontroller (SMD ceramics for 10µF) **$20.00**

MICROMITE LCD BACKPACK V2 – COMPLETE KIT (CAT SC4237) *(MAY'17)*
includes PCB, programmed micro, touchscreen LCD, laser-cut UB3 lid, mounting hardware, SMD Mosfets for PWM backlight control and all other on-board parts **$70.00**

SC200 AMPLIFIER MODULE (CAT SC4140) *(JAN'17)*
hard-to-get parts: 0R-01R, DD-D4, 150pF/250V capacitor and five SMD resistors **$35.00**

VARIOUS MODULES & PARTS

MCP1700 3.3V LDO regulator (isolated Serial Link, JAN19 etc) **$1.50**
LM4865MX amplifier IC & LF505V regulator (Tinnitus/Insomnia Killer, NOV18) **$10.00**
2.8-inch touchscreen LCD module with SD card socket (Tide Clock, JUL18) **$22.50**
ESP-01 WiFi Module (El Cheapo Modules, Part 15, APR18) **$5.00**
WiFi Antennas with U.FL/IPX connectors (Watt Tank Level Meter with WiFi, FEB18): 5dBi – **$12.50** – 2dBi (omnidirectional) – **$10.00**
NRF24L01+PA+LNA transceiver with SMA connector and antenna (El Cheapo 12, JAN18) **$5.00**
WeMos D1 Arduino-compatible boards with WiFi (SEPT17, FEB18):
ThingSpeak data logger – **$10.00** – WiFi Tank Level Meter (ext. antenna socket) – **$15.00**
Geeetech Arduino MP3 shield (Arduino Music Player/Recorder, VS1053, JUL17) **$20.00**
1nF 1% MKP (5mm lead spacing) or ceramic capacitor (Wide-Range LC Meter, JUN18) **$2.50**
MAX7219 LED controller boards (El Cheapo Modules, Part 7, JUN17):
8x8 red SMD/DIP matrix display – **$5.00** – red 8-digit 7-segment display – **$7.50**
AD9833 DDS module (with gain control) (El Cheapo Modules, APR17) **$25.00**
AD9833 DDS module (no gain control) (El Cheapo Modules, Part 6, APR17) **$15.00**
CP2102 USB-UART bridge **$5.00**
microSD card adaptor (El Cheapo Modules, Part 3, JAN17) **$2.50**
DS3231 real-time clock with mounting spacers and screws (El Cheapo, Part 1, OCT16) **$5.00**

MICROMITE PLUS EXPLORE 100 COMPLETE KIT (no LCD panel) *(SEP'16)*
(includes PCB, programmed micro and the hard-to-get bits including female headers, USB and microSD sockets, crystal, etc but does not include the LCD panel) (Cat SC3834) **$69.90**

THESE ARE ONLY THE MOST RECENT MICROS AND SPECIALISED COMPONENTS. FOR THE FULL LIST, SEE www.siliconchip.com.au/shop

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01/19

PRINTED CIRCUIT BOARDS

NOTE: The listings below are for the PCB ONLY. If you want a kit, check our store or contact the kit suppliers advertising in this issue. For unusual projects where kits are not available, some have specialised components available – see the list opposite.

NOTE: Not all PCBs are shown here due to space limits but the SILICON CHIP Online Shop has boards going back to 2001 and beyond. For a complete list of available PCBs etc, go to *siliconchip.com.au/shop/3* Prices are PCBs only, NOT COMPLETE KITS!

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
NICAD/NIMH BURP CHARGER	MAR 2014	14103141	$15.00
RUBIDIUM FREQ. STANDARD BREAKOUT BOARD	APR 2014	04101141	$10.00
USB/RS232C ADAPTOR	APR 2014	07103141	$5.00
MAINS FAN SPEED CONTROLLER	MAY 2014	10104141	$10.00
RGB LED STRIP DRIVER	MAY 2014	16105141	$10.00
HYBRID BENCH SUPPLY	MAY 2014	18104141	$20.00
2-WAY PASSIVE LOUDSPEAKER CROSSOVER	JUN 2014	01205141	$20.00
TOUCHSCREEN AUDIO RECORDER	JUL 2014	01105141	$12.50
THRESHOLD VOLTAGE SWITCH	JUL 2014	99106141	$10.00
MICROMITE ASCII VIDEO TERMINAL	JUL 2014	24107141	$7.50
FREQUENCY COUNTER ADD-ON	JUL 2014	04105141a/b	$15.00
TEMPMASTER MK3	AUG 2014	21108141	$15.00
44-PIN MICROMITE	AUG 2014	24108141	$5.00
OPTO-THEREMIN MAIN BOARD	SEP 2014	23108141	$15.00
OPTO-THEREMIN PROXIMITY SENSOR BOARD	SEP 2014	23108142	$5.00
ACTIVE DIFFERENTIAL PROBE BOARDS	SEP 2014	04107141-2	$10.00/set
MINI-I3 AMPLIFIER	SEP 2014	01110141	$5.00
COURTESY LIGHT DELAY	OCT 2014	05109141	$7.50
DIRECT INJECTION (DI) BOX	OCT 2014	23109141	$5.00
DIGITAL EFFECTS UNIT	OCT 2014	01110131	$15.00
DUAL PHANTOM POWER SUPPLY	NOV 2014	18112141	$10.00
REMOTE MAINS TIMER	NOV 2014	19112141	$10.00
REMOTE MAINS TIMER PANEL/LID (BLUE)	NOV 2014	19112142	$15.00
ONE-CHIP AMPLIFIER	NOV 2014	01109141	$5.00
TDR DONGLE	DEC 2014	04112141	$5.00
MULTISPARK CDI FOR PERFORMANCE VEHICLES	DEC 2014	05112141	$10.00
CURRAWONG STEREO VALVE AMPLIFIER MAIN BOARD	DEC 2014	01111141	$50.00
CURRAWONG REMOTE CONTROL BOARD	DEC 2014	01111144	$5.00
CURRAWONG FRONT & REAR PANELS	DEC 2014	01111142/3	$30.00/set
CURRAWONG CLEAR ACRYLIC COVER	JAN 2015	SC2892	$25.00
ISOLATED HIGH VOLTAGE PROBE	JAN 2015	04108141	$10.00
SPARK ENERGY METER MAIN BOARD	FEB/MAR 2015	05101151	$10.00
SPARK ENERGY ZENER BOARD	FEB/MAR 2015	05101152	$10.00
SPARK ENERGY METER CALIBRATOR BOARD	FEB/MAR 2015	05101153	$5.00
APPLIANCE INSULATION TESTER	APR 2015	04102151	$10.00
APPLIANCE INSULATION TESTER FRONT PANEL	APR 2015	04102152	$10.00
LOW-FREQUENCY DISTORTION ANALYSER	APR 2015	04104151	$5.00
APPLIANCE EARTH LEAKAGE TESTER PCBs (2)	MAY 2015	04203151/2	$15.00
APPLIANCE EARTH LEAKAGE TESTER LID/PANEL	MAY 2015	04203153	$15.00
BALANCED INPUT ATTENUATOR MAIN PCB	MAY 2015	04105151	$15.00
BALANCED INPUT ATTENUATOR FRONT & REAR PANELS	MAY 2015	04105152/3	$20.00
4-OUTPUT UNIVERSAL ADJUSTABLE REGULATOR	MAY 2015	18105151	$5.00
SIGNAL INJECTOR & TRACER	JUNE 2015	04106151	$7.50
PASSIVE RF PROBE	JUNE 2015	04106152	$2.50
SIGNAL INJECTOR & TRACER SHIELD	JUNE 2015	04106153	$5.00
BAD WIRES INFRASOUND SNOOPER	JUNE 2015	04104151	$5.00
CHAMPION + PRE-CHAMPION	JUNE 2015	01109121/2	$7.50
DRIVEWAY MONITOR TRANSMITTER PCB	JULY 2015	15105151	$10.00
DRIVEWAY MONITOR RECEIVER PCB	JULY 2015	15105152	$5.00
MINI USB SWITCHMODE REGULATOR	JULY 2015	18107151	$2.50
VOLTAGE/RESISTANCE/CURRENT REFERENCE	AUG 2015	04108151	$2.50
LED PARTY STROBE MK2	AUG 2015	16101141	$7.50
ULTRA-LD MK4 200W AMPLIFIER MODULE	SEP 2015	01107151	$15.00
9-CHANNEL REMOTE CONTROL RECEIVER	SEP 2015	15108151	$15.00
MINI USB SWITCHMODE REGULATOR MK2	SEP 2015	18107152	$2.50
2-WAY PASSIVE LOUDSPEAKER CROSSOVER	OCT 2015	01205141	$20.00
ULTRA LD AMPLIFIER POWER SUPPLY	OCT 2015	01109111	$15.00
ARDUINO USB ELECTROCARDIOGRAPH	OCT 2015	07108151	$7.50
FINGERPRINT SCANNER – SET OF TWO PCBS	NOV 2015	03109151/2	$15.00
LOUDSPEAKER PROTECTOR	NOV 2015	01110151	$10.00
LED CLOCK	DEC 2015	19110151	$15.00
SPEECH TIMER	DEC 2015	19111151	$15.00
TURNTABLE STROBE	DEC 2015	04101161	$5.00
CALIBRATED TURNTABLE STROBOSCOPE ETCHED DISC	DEC 2015	04101162	$10.00
VALVE STEREO PREAMPLIFIER – PCB	JAN 2016	01101161	$15.00
VALVE STEREO PREAMPLIFIER – CASE PARTS	JAN 2016	01101162	$20.00
QUICKBRAKE BRAKE LIGHT SPEEDUP	JAN 2016	05102161	$5.00
SOLAR MPPT CHARGER & LIGHTING CONTROLLER	FEB/MAR 2016	16101161	$15.00
MICROMITE LCD BACKPACK, 2.4" INCH VERSION	FEB/MAR 2016	07102121	$7.50
MICROMITE LCD BACKPACK, 2.8-INCH VERSION	FEB/MAR 2016	07102122	$7.50
BATTERY CELL BALANCER	MAR 2016	11111151	$6.00
DELTA THROTTLE TIMER	MAR 2016	05102161	$15.00
MICROWAVE LEAKAGE DETECTOR	APR 2016	04103161	$5.00
FRIDGE/FREEZER ALARM	APR 2016	03104161	$5.00
ARDUINO MULTIFUNCTION MEASUREMENT	APR 2016	04116101/2	$15.00
PRECISION 50/60Hz TURNTABLE DRIVER	MAY 2016	04104161	$15.00
RASPBERRY PI TEMP SENSOR EXPANSION	MAY 2016	24104161	$5.00
100dB STEREO AUDIO LEVEL/VU METER	JUN 2016	01104161	$15.00
HOTEL SAFE ALARM	JUN 2016	03106161	$5.00
UNIVERSAL TEMPERATURE ALARM	JULY 2016	03105161	$5.00
BROWNOUT PROTECTOR MK2	JULY 2016	10107161	$10.00
8-DIGIT FREQUENCY METER	AUG 2016	04105161	$10.00

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
APPLIANCE ENERGY METER	AUG 2016	04116061	$15.00
MICROMITE PLUS EXPLORE 64	AUG 2016	07108161	$5.00
CYCLIC PUMP/MAINS TIMER	SEPT 2016	10108161/2	$10.00/pair
MICROMITE PLUS EXPLORE 100 (4 layer)	SEPT 2016	07109161	$20.00
AUTOMOTIVE FAULT DETECTOR	SEPT 2016	05109161	$10.00
MOSQUITO LURE	OCT 2016	25101161	$5.00
MICROPOWER LED FLASHER	OCT 2016	16109161	$5.00
MINI MICROPOWER LED FLASHER	OCT 2016	16109162	$2.50
50A BATTERY CHARGER CONTROLLER	NOV 2016	11111161	$10.00
PASSIVE LINE TO PHONO INPUT CONVERTER	NOV 2016	01111161	$5.00
MICROMITE PLUS LCD BACKPACK	NOV 2016	07110161	$7.50
AUTOMOTIVE SENSOR MODIFIER	DEC 2016	05111161	$10.00
TOUCHSCREEN VOLTAGE/CURRENT REFERENCE	DEC 2016	04110161	$12.50
SC200 AMPLIFIER MODULE	JAN 2017	01108161	$10.00
60V 40A DC MOTOR SPEED CON. CONTROL BOARD	JAN 2017	11112161	$10.00
60V 40A DC MOTOR SPEED CON. MOSFET BOARD	JAN 2017	11112162	$12.50
GPS SYNCHRONISED ANALOG CLOCK	FEB 2017	04202171	$10.00
ULTRA LOW VOLTAGE LED FLASHER	FEB 2017	16110161	$2.50
POOL LAP COUNTER	MAR 2017	19102171	$15.00
STATIONMASTER TRAIN CONTROLLER	MAR 2017	09103171/2	$15.00/set
EFUSE	APR 2017	04102171	$7.50
SPRING REVERB	APR 2017	01104171	$12.50
6GHz+ 1000:1 PRESCALER	MAY 2017	04112162	$7.50
MICROBRIDGE	MAY 2017	24104171	$2.50
MICROMITE LCD BACKPACK V2	MAY 2017	07104171	$7.50
10-OCTAVE STEREO GRAPHIC EQUALISER PCB	JUN 2017	01105171	$12.50
10-OCTAVE STEREO GRAPHIC EQUALISER FRONT PANEL	JUN 2017	01105172	$15.00
10-OCTAVE STEREO GRAPHIC EQUALISER CASE PIECES	JUN 2017	SC4281	$15.00
RAPIDBRAKE	JUL 2017	05105171	$10.00
DELUXE EFUSE	AUG 2017	18106171	$15.00
DELUXE EFUSE UB1 LID	AUG 2017	SC4316	$5.00
MAINS SUPPLY FOR BATTERY VALVES (INC. PANELS)	AUG 2017	18108171-4	$25.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER	SEPT 2017	01108171	$20.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER PANELS	SEPT 2017	01108172/3	$20.00/pair
3-WAY ADJUSTABLE ACTIVE CROSSOVER CASE PIECES	SEPT 2017	SC4403	$10.00
6GHz+ TOUCHSCREEN FREQUENCY COUNTER	OCT 2017	04110171	$15.00
KELVIN THE CRICKET	OCT 2017	08109171	$10.00
6GHz+ FREQUENCY COUNTER CASE PIECES (SET)	DEC 2017	SC4444	$15.00
SUPER-7 SUPERHET AM RADIO PCB	DEC 2017	06111171	$25.00
SUPER-7 SUPERHET AM RADIO CASE PIECES	DEC 2017	SC4464	$25.00
THEREMIN	JAN 2018	23112171	$12.50
PROPORTIONAL FAN SPEED CONTROLLER	JAN 2018	05111171	$2.50
WATER TANK LEVEL METER (INCLUDING HEADERS)	FEB 2018	21110171	$7.50
10-LED BARAGRAPH	FEB 2018	04101181	$7.50
10-LED BARAGRAPH SIGNAL PROCESSING	FEB 2018	04101182	$5.00
TRIAC-BASED MAINS MOTOR SPEED CONTROLLER	MAR 2018	10102181	$10.00
VINTAGE TV A/V MODULATOR	MAR 2018	02104181	$7.50
AM RADIO TRANSMITTER	MAR 2018	06101181	$7.50
HEATER CONTROLLER	APR 2018	10104181	$10.00
DELUXE FREQUENCY SWITCH	MAY 2018	05104181	$7.50
USB PORT PROTECTOR	MAY 2018	07105181	$2.50
2 x 12V BATTERY BALANCER	MAY 2018	14106181	$2.50
USB FLEXTIMER	JUNE 2018	19106181	$7.50
WIDE-RANGE LC METER	JUNE 2018	04106181	$5.00
WIDE-RANGE LC METER (INCLUDING HEADERS)	JUNE 2018	SC4618	$7.50
WIDE-RANGE LC METER CLEAR CASE PIECES	JUNE 2018	SC4609	$7.50
TEMPERATURE SWITCH MK2	JUNE 2018	05105181	$7.50
LiPo/Pb UPS CONTROL SHIELD	JULY 2018	11106181	$5.00
RASPBERRY PI TOUCHSCREEN ADAPTOR (TIDE CLOCK)	JULY 2018	24108181	$5.00
RECURRING EVENT REMINDER	JULY 2018	19107181	$5.00
BRAINWAVE MONITOR (EEG)	AUG 2018	25107181	$10.00
SUPER DIGITAL SOUND EFFECTS	AUG 2018	01107181	$2.50
DOOR ALARM	AUG 2018	03107181	$5.00
STEAM WHISTLE / DIESEL HORN	SEPT 2018	09106181	$5.00
DCC PROGRAMMER	OCT 2018	09107181	$5.00
DCC PROGRAMMER (INCLUDING HEADERS)	OCT 2018	09107181	$7.50
OPTO-ISOLATED RELAY (WITH EXTENSION BOARDS)	OCT 2018	10107181/2	$7.50
GPS-SYNCHED FREQUENCY REFERENCE	NOV 2018	04107181	$7.50
1 x LED CHRISTMAS TREE	NOV 2018	16107181	$5.00
4 x LED CHRISTMAS TREE			$18.00
18 x LED CHRISTMAS TREE			$72.00
31 x LED CHRISTMAS TREE			$120.00
38 x LED CHRISTMAS TREE			$145.00
DIGITAL INTERFACE MODULE	NOV 2018	16107182	$2.50
TINNITUS/INSOMNIA KILLER (JAYCAR VERSION)	NOV 2018	01110181	$5.00
TINNITUS/INSOMNIA KILLER (ALTRONICS VERSION)	NOV 2018	01110182	$5.00
HIGH-SENSITIVITY MAGNETOMETER	DEC 2018	04101011	$12.50
USELESS BOX	DEC 2018	08111181	$7.50
FOUR-CHANNEL DC FAN & PUMP CONTROLLER	DEC 2018	05108181	$5.00
NEW PCBs			
Attiny816 DEVELOPMENT/BREAKOUT BOARD	**JAN 2019**	**24118181**	**$5.00**
ISOLATED SERIAL LINK	**JAN 2019**	**24107181**	**$5.00**

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Got a technical problem? Can't understand a piece of jargon or some technical principle? Drop us a line and we'll answer your question. Send your email to silicon@siliconchip.com.au

LED Tree software does not provide a simulation

I just received and read the latest issue (December 2018), and with particular interest, the article on page 38 titled "Amazing Light Patterns for the LED Christmas Tree" by Tim Blythman (siliconchip.com.au/Article/11333). I am unsure if one can use the LED Tree Data Map Program to show the patterns without having the physical LED Tree connected.

I have played with the Processing IDE and can see how it will let you build a tree and a display pattern(s) but cannot find a way to have the program run the desired light show on the Tree displayed on the screen. It would appear the program is one way, which is a pity. Perhaps I have got it wrong, if so could you enlighten me? (H. Y., Bruthen, Vic)

- You are correct, there is no way to play back a sequence from inside the program. The program described is intended purely as a way to build software which can effectively address LEDs in your tree by their physical location. Once you have designed a sequence based on that data, you need to connect your actual LED Tree to test out the patterns.

Beginner looking to tackle SC200 project

I am interested in building a stereo amplifier using your SC200 module design (January-March 2017; siliconchip.com.au/Series/308). Would this be possible (or recommended) for someone like me, who can solder, but is only a beginner when it comes to electronics? I would like to get your opinion before I purchase any kits. (M. K., via email)

- A relative beginner should not have too much difficulty building the SC200. The main thing to watch out for is to make sure your soldering is good and you are using good quality tools, such as a temperature-controlled soldering iron.

You need to observe each solder joint as it is made, and ensure that the solder has properly flowed onto both the PCB pad and the component pin. It forms a particular shape, with a flat base on the board, tapering to a point where the component lead emerges. This is known as a "fillet".

You can find images showing what a good through-hole fillet should look like on the internet, for example, at this page: siliconchip.com.au/link/aamc

The other thing is to take your time and follow all the instructions carefully, ensuring that all the components are placed where shown, with the correct orientation (for polarised components) and that you don't leave anything out.

As long as you follow our instructions carefully, you should be able to build the SC200 successfully.

Usually, if you follow the instructions, it will work the first time. But if it doesn't, you will need to understand how to troubleshoot the board and figure out what has gone wrong.

Faults are typically due to a soldering problem, incorrectly placed component or a faulty component (rare, but it does happen).

In that case, if you can't figure it out, we will try to help but it can be difficult to guide people through troubleshooting remotely.

But don't let that scare you. Many of these amplifier modules have been built (it's in the hundreds) and we have not had many people run into difficulties.

Warning when programming PIC

I am currently building the Steam Train Whistle or Diesel Horn that appears in the September 2018 issue of your excellent magazine (siliconchip.com.au/Article/11281).

I am using a PICkit 3 to program the PIC12F617 ICs. The white noise file works perfectly but attempting to load the Whistle/Horn firmware produces the following message:

"The PICkit 3 does not support programming this device if both the internal oscillator and internal MCLR are selected.

You may continue programming but you are encouraged to cancel, reconfigure your device and try again. Select OK to continue programming or cancel to avoid programming."

So far I have only pressed cancel. How do I solve this problem? (L. K., Ashby, NSW)

- That warning is normal when programming this firmware, since it uses the MCLR pin as an I/O. Just ignore the warning and press OK when it appears. That's what we do and the PIC12F617 programs successfully.

See page 80 of the August 2018 issue for more details.

Equivalent for an old thyristor wanted

We have an 80s-vintage Dunlite 35kVA generator. It's driven by a Ford diesel engine. The regulator board is a UVR100 and it has failed. It's now obsolete. A replacement board with model number AVR380 is available but it's about $800.

The problem appears to be the 2N6170 stud-mount thyristor. Do you know of an equivalent device? Does anyone have a circuit diagram for these old boards? SCOOP control is fascinating for those interested in generator control. Thanks to SILICON CHIP for helping to keep us abreast with the latest electronics. (M. R., via email)

- We searched extensively but unfortunately, could not find a modern equivalent of the 2N6170. The problem is that stud mount SCRs are still available but it's unusual to find one with an isolated stud, and we can't find any isolated stud SCRs with similar ratings.

The only thing we can think of is that you could replace the 2N6170 with an SCR that has similar ratings but is in a different type of isolated package and bolt it to the same heatsink, then wire it up similarly.

The 2N6170 is rated to handle up to 13A continuous and 560A peak at 600V. The maximum gate trigger current is 75mA. We found about 30 suitable replacement devices. For example, the STMicro TM8050H-8W is rated at 800V, 50A continuous, 670A peak with a maximum gate trigger current of 50mA. It comes in a TO-247 package so you would need an insulator between it and the heatsink.

Other possibilities include the ST-Micro BTW67-600 in a chassis-mounting RD91 case, the IXYS CS30-14IQ1 in an insulated TO-247 case (no added insulation required) and the Vishay VS-30TPS16LHM3, again in an insulated TO-247 case. Most of these parts cost around $5.

With a bit of ingenuity, you may be able to repair your generator using one of these components.

Components left over after building kit

I am hoping you can help me. I recently built the 12-48V 40A DC Motor Speed Controller published in your January and February 2017 issues (**siliconchip.com.au/Series/309**) using the Jaycar KC5534 kit. This is not something I have done before but thought I would give it a go.

I have made it the majority of the way through building the first power board but I have a few resistors and diodes left over and I am not sure where they should go. Can you please give me some guidance as to how to finish the board and to make sure I have got everything correct so far. I have followed the instructions but with my limited knowledge, it is hard to know what I missed.

Some of the parts I have left over are: two shorting blocks, a four-pin header, a pushbutton, six resistors and two diodes. (C. M., via email)

- The left over resistors and zener diodes are for when you have a supply voltage other than 12V. See the details screen printed on the right-hand end of PCB for the 24V, 36V and 48V options.

The four header pins are for jumpers JP1 and JP2. Snap the 4-way header into two 2-way headers. The jumper shunts (rectangular blocks) can then go onto these headers if required.

Fit the switch in the lower-left corner of the board, below the shutdown button terminal block. From the photo you sent, we can also see that you've forgotten to fit the 4.7Ω resistor below IC2.

Faulty boost regulator in DCC Programmer

I just recently got around to assembling your Arduino-based DCC Programming Shield, as published in the October 2018 issue (**siliconchip.com.au/Article/11261**).

The problem I have is that the MT3608 step-up regulator that I purchased from your Online Shop appears to be faulty. It's producing a constant 4.9V at its output and this cannot be changed by adjusting the pot. (M. M., Burleigh Waters, Qld)

- It certainly sounds like your MT3608 module is faulty and is just feeding the 5V input straight through without boosting it. We can send you a replacement module to see if that fixes your issue.

Sourcing hard to find semiconductors

I'm working on two SILICON CHIP projects and have found that two semiconductors are hard to find from the suppliers I usually use. The two projects are listed below, with the semiconductors:

4N28 optocoupler: Solar MPPT Charger/Lighting Controller (February-March 2016; **siliconchip.com.au/Series/296**).

MC14584 hex schmitt trigger inverter: Stationmaster train controller (March 2017; **siliconchip.com.au/Article/10575**).

For the 4N28 optocoupler, 4N25 is also listed when I search for the 4N28, would this be an equivalent part?

Current flow through solar cells connected in series

When we connect solar cells in series, the voltages add up. But what happens with the current flow? Obviously, it does not add up.

I have asked a few electricians this question and none of them have been able to provide a satisfactory answer. Thank you for any explanation you can provide. (M. R., via email)

- With the cells in series, the full current must pass through each one.

This presents a problem with large panels that consist of many smaller cells in series, since if part of the panel is in shade, current cannot flow through some of the cells and so the overall panel output is significantly reduced.

This is typically solved by having power schottky diodes across each group of cells. Current therefore bypasses cells which are not producing power, flowing through the diode instead. Schottky diodes have a low forward voltage, so the panel output is close to optimum.

Each cell in a solar panel usually produces around 0.5V, so a typical 12V (nominal) solar panel usually consists of around 36 cells, and a 24V panel has typically around 72 cells.

These are normally grouped into sets of around 18 cells, which are physically located in a strip. Each of these groups has a schottky bypass diode.

For example, if you have a 240W/24V panel which consists of four groups of 18 cells in series, you might have two groups in full sunlight producing 9V/6.5A and the other two in shade, producing no power.

So the panel output would be 17V ($2 \times 9V - 2 \times 0.5V$) with 6.5A current flow, for a total power of 110.5W. That isn't much less than half the nominal power, which is pretty good if only half the panel is in sunlight.

In this case, each schottky diode would dissipate around 3.25W. Without the diodes, you would get little or no output from the panel in that situation.

Virtually all panels available today should have the integrated schottky diodes as they are a cheap way to ensure close-to-maximum output under all conditions.

If you're connecting panels in series, it's a good idea to bypass each with a schottky diode too (with a suitable voltage and current rating), in case whole panels in the string are in shade while others are producing power.

I've tried Jaycar, Altronics, Element14, RS, Mouser & Digi-Key. It looks like the 4N28 is available from Mouser & Digikey, but it wouldn't be cost effective to buy just one from them due to the postage cost. The MC14584 looks like it is only available in an SMD package, not through hole.

Do you have suggestions on where to source these parts? Thank you. (P. C., via email)

● Altronics and Jaycar do sell the 4N28 optocoupler (Altronics Z1645; Jaycar ZD1928). You can also buy the optocoupler and through-hole inverter IC from Futurlec: www.futurlec.com/Motorola/MC14584BCPpr.shtml

www.futurlec.com/LED/4N28pr.shtml

No output from Heater Controller

I have built the Thermopile-based Heater Controller (April 2018; siliconchip.com.au/Article/11027) but I cannot get it to work. I built it in percentage control mode.

I have replaced all the components, soldered all the through-holes on both sides, removed the PIC and traced all the PCB tracks out with an ohmmeter.

The output is completely dead. I probed the board with my Fluke 117 multimeter. Oddly, when I measured the supply voltage between pins 1 and 8 of IC1, the lamp load illuminated but at reduced brightness. It appears to only be operating in half-wave conduction, as the output voltage measures 129VAC in this condition.

Adjusting VR1 has an effect but not the expected one. Setting it fully anticlockwise gives maximum output and fully clockwise, no output. The adjustment is not very progressive; the output is essentially on or off.

I get the following measurements with the PIC out of circuit: 5.1V test point 4.8V, V+ test point 5.6V, active in 239VAC, active out 0VAC, voltage across 1kΩ resistor 34.9VAC.

To verify that the Triac would conduct on both half-cycles, I left PIC IC1 out and shorted pin 1 to pin 2. I then took the following readings with a 300W lamp load. 5.1V test point 0.913V, V+ test point 1.62V, active in 235VAC, active out 235VAC, voltage across 1kΩ resistor 34.5VAC.

It appears that the 5.1V supply is not capable of delivering enough current for the PIC and the Triac trigger current. (F. T., Narrabeen, NSW)

● That the Triac is only driven when you probe IC1's supply suggests that there is a bad connection between the PCB and IC1, possibly in the socket, or a problem with the 100nF bypass capacitor across this supply.

Your testing verifies that the Triac can operate in full wave mode. However, it isn't a fair test to see if the 5V supply is capable of maintaining 5V when driving the Triac continuously. When operating as designed, the Triac is only driven for a brief period within the mains cycle and not the whole cycle as in your test.

The 5V supply is not capable of supplying the gate current over the full cycle but when operating normally, that is not required.

We are not aware of any problems with the design and suspect you may have a problem with your PIC12F675. It is also possible that your PIC chip has not been programmed correctly so please verify that.

Explore 100 not responding over USB

I have recently completed the Explore 100 project (September and October 2016; siliconchip.com.au/Series/304) but am having trouble communicating via the USB console.

I am using Windows 10 and Tera Term and cannot get the keystrokes to register in the terminal window. I am not sure if you offer advice but you could point me in the right direction. (J. A., Townsville, Qld)

● The first thing you should do is to check whether IC1 is working. Your problem could be due to a faulty solder joint on the USB connector (CON2) or IC1, a power supply problem, a problem with one of the components required for IC1 to operate such as crystal X1 or the 10µF SMD ceramic capacitor and so on.

We suggest that you connect a USB/serial adaptor to your PC and wire it up to CON6 as shown in the circuit diagram on pages 80 and 81 of the September 2016 issue.

See if you can establish communications with the chip using that serial port. If you can then that shows that IC1 is working OK and your problem is most likely with CON2 or the configuration on your PC.

Building a through-hole version of the Battery Lifesaver

I am keen to build your Battery Lifesaver project from the September 2013 issue (siliconchip.com.au/Article/4360); however, I am incapable of managing SMD components.

I have tried! Can you give me provide part numbers for through-hole equivalents of the following parts, so I can build the circuit using these parts?

D1,D2: BAT54C

REG1: MCP1703T-5002-E/CB

IC1: MCP6541

Q1: PSMN1R2-30YL

There doesn't seem to be any special layout requirements in this simple circuit, save heavy duty wiring as appropriate. I am a long time supporter of SILICON CHIP and would be very grateful for your help. (C. O'D., Adelaide, SA)

● There is no direct through-hole equivalent of many of the parts that you've mentioned but it is possible to find parts that are similar enough to do the job.

For each BAT54C, you could substitute two 1N5819s. This is overkill but if you buy from Jaycar or Altronics, you won't save any money getting a lower-current schottky diode so you might as well use these.

For the MCP1703-5002E/CB, the only similar through-hole device we can find is the S-812C50AY-B2-U which is available from Digi-Key and Mouser. It can't deliver as much output current but that shouldn't matter.

The MCP6541 is available as 8-pin DIP (MCP6541-I/P) or there is the TLV3701IP which is functionally similar and also available in DIP-8.

For the PSMN1R2-30YL, you can use any low on-resistance logic-level Mosfet with a high enough voltage and current rating. The PSMN1R1-30PL is a good candidate.

You are right that the only real layout consideration for this project is keeping the high-current path resistance as low as possible.

If you can't get either console to work then that strongly suggests that IC1 is not operating properly. See the troubleshooting steps on page 83 of the October 2016 issue, and for more detail, see the Explore 64 article in the August 2016 issue.

Basically, you should measure the current draw of the board with nothing attached (including the LCD). You can expect it to be around 90-100mA. If it's well outside that range then IC1 is not working correctly and you will need to check your soldering and component placement carefully.

Using dimmer with fluorescent tubes

I have a question about the Touch and/or Remote-controlled Light Dimmer project by John Clarke, published in your January and February 2002 issues (siliconchip.com.au/Series/116).

I have been successfully dimming a fluorescent tube array, using earlier ETI dimmer projects. In this application, the tube filaments are separately supplied. The facility was abandoned after several years, partly due to technical issues with the fluorescent tubes.

I've now resurrected the concept, this time using the 2002 Touchplate dimmer. I built the kit exactly as described in the February 2002 article. The unit works as described (having been reluctantly installed by an electrician).

However, I am having some difficulties, I suspect due to the age and condition of the 40W preheat tubes originally installed.

It had been my experience that periodic cleaning of tubes to remove dust and grime is desirable in maintaining smooth dimming operation.

But aging tubes also seem to contribute to flickering when dimmed. It should be simple to fix this – just replace the tubes. But 40W preheat tubes are no longer available! Now 36W tubes are the norm. Can 36W tubes be dimmed?

Another factor arises with the use of 36W slimline (T5) tubes, with a smaller diameter than the 40W T8 tubes. In the past, following recommendations on dimming control of fluorescent tubes, I installed an Earthed metal tray along the length of the fluorescent tube array. This was supposed to enhance triggering of the discharge.

With the use of 36W tubes, the spacing between the Earthed tray and the surface of the tubes is now much greater. Will that affect the dimming performance, or is it irrelevant?

Is there any reason why the Touchplate couldn't be used in fluorescent dimming applications? In practice, it almost does work, subject to fluorescent tube condition. (B. G., Mt. Waverly, Vic)

- Yes, 36W fluorescent tubes can be dimmed using the 2002 dimmer design, as long as the preheat filaments are driven separately as you are doing. The Earthed ground plane needs to be 12.7mm away from the tube, so if the 36W tubes are too far away, the strip will need to be moved closer.

Help finding sewing machine thyristor

I'm looking for any details on a replacement or similar thyristor to the one I have in a computer-controlled sewing machine.

It's a 3-pin low-power thyristor with the marking "TAG8706" on it. The sewing machine is a Durkopp Adler 867-classic.

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Dodgy soldering may have caused downlight failure

I am sending you a photo I took of a PCB removed from an LED downlight that failed after being in operation for one to two years (see photo). It was one of a pair in the room and there was never any discernible difference in the two. When it failed, I had to open it and have a look.

It looks like two SMD resistors are piggybacked – or could it be an assembly error? Is there only supposed to be one component there? The board looks a little charred/discoloured around these components. (R. W. King Creek, NSW)

● It looks like there are supposed to be two resistors there as the PCB is labelled "RS2 RS1" but maybe they were supposed to be soldered side-by-side rather than stacked.

That would make sense, since the benefit of two 0.2Ω resistors in parallel rather than a single 0.1Ω resistor is the increase in total safe dissipation, and that will be much less effective if one is on top of the other.

It looks like they've used some sort of red glue or wax to hold the components down while soldering and perhaps that has failed on one of the resistors, allowing solder surface tension to pull it on top of the other. That could also explain why they're soldered askew.

It's hard to say whether that could have caused the fault. As you say, there seems to be some charring on and around the bottom resistor.

We would remove both, clean up that area of the board and replace them with 0.2Ω resistors of a similar size and the highest power rating available, mounted side by side, and see if that fixes the downlight. If that doesn't fix it, you will have to go searching for other causes.

By the way, you could open up the identical working downlight to see whether it has a similar arrangement, but that would presumably be quite a bit of extra work for you.

Anyone with details on this thyristor please contact me at 04 2574 871 (B. F., East Malvern, Vic)

● We did some searching but couldn't find any details on this thyristor. However, we did find the parts list (in German) at **siliconchip.com.au/link/aami**

GPS Clock stops at five minutes to 12

I built your GPS Analog Clock but I have a problem with it. It occasionally stops at five minutes to 12 and never restarts until I pull out the batteries and leave them out for a minute, and also disconnect the GPS module and re-connect it. The LEDs will then blink and it will run as normal for some time. (R. C., Lennox Head, NSW)

● You haven't said which GPS Analog Clock you've built. There was one published in the March 2009 issue, one in the November 2009 issue and one in the February 2017 issue (**siliconchip.com.au/Article/10527**).

You also haven't said whether you've built the version for clocks with stepping hands or sweep hands; they behave differently. Regardless, the following is mentioned on page 30 of the February 2017 issue.

Clocks with stepping hands will stop at exactly 12 o'clock if the battery voltage is too low. They will stop at five minutes to 12 if the GPS signal lock is lost and at 10 minutes to 12 if GPS module communication is lost.

So it seems that your GPS signal is marginal. You may need a more sensitive receiver, or to change its position slightly, or use one with an external antenna.

Strange behaviour from Wideband Controller

I just finished building the Wideband Oxygen Sensor Controller Mk2 from the June-August 2012 issues (**siliconchip.com.au/Series/23**), using a PCB and programmed microcontroller purchased from the SILICON CHIP Online Shop. I have gone through all the set-up steps.

When I power it up with all ICs in place and no oxygen sensor connected, the LED lights up dull straight away. After about three seconds, it flashes brighter for half a second, then goes back to being dull. It stays dull from then on.

In the article, it says that with the sensor unplugged, the LED should light at full brightness for four seconds and then flashes at 1Hz, indicating an error with the sensor connection.

That's not happening on my unit. Is it possible my PIC is faulty? Do you have any other ideas what might be wrong? (S. T., Mylor, SA)

● It would seem the PIC is working, at least a little. It's very odd that it lights up dimly at first. Perhaps there is a short on the PCB that also powers the LED.

It is very unusual that a PIC is faulty, but it can happen. Check your construction carefully, particularly around the LED drive at pin 6. Is the 5V supply output voltage correct?

If you still can't get it to work, we will send you a replacement PIC. If that fixes it then you know the PIC was at fault. Otherwise, you will have to continue looking for another cause.

GPS Tracker stopped working

I built the GPS Tracker project, published in the November 2013 issue (**siliconchip.com.au/Article/5449**) from a Jaycar kit (Cat KC5525). It worked perfectly for a while, then on Saturday, it stopped working and it now refuses to lock onto the GPS signal.

The GPS LED flashes slowly but will not stay on, with the momentary flicker to indicate log recording. Do you know what might have gone wrong? (Anon, via email)

● We asked Geoff Graham for ideas and he said: a slow flashing LED means that the GPS tracker is alive and it can detect the GPS module but the module is not getting a fix on enough satellites to report an accurate position.

The most likely causes are a faulty GPS module or a faulty supercap. Other possibilities include a fault on the

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3.3V power line or faulty Mosfet (Q1).

Ferrite bead impedance/ resistance requirement

I have a query regarding your 6GHz+ Frequency Counter Parts list (**siliconchip.com.au/Series/319**).

On page 33 of the October 2017 issue, the parts list calls for a "low resistance SMD ferrite bead". As I was ordering most of my parts from Digi-Key Electronics, I also ordered a ferrite bead, Cat 240-2411-1-ND.

However, I now realise that this ferrite bead has a resistance of 160Ω and looking at the circuit, I can see that it is part of a pi filter feeding a couple of regulators.

Not knowing the exact current draw, I am guessing that the voltage drop is going to be excessive across this ferrite bead.

Could you let me know what ferrite bead was used for this project, eg, the part number and supplier? (J. T., Redwood Park, SA)

- According to the specifications on the Digi-Key website, 160Ω is the impedance of the ferrite bead at the test frequency, which in this case is 100MHz (a typical test frequency).

The requirement for "low resistance" in this project is that it must have a low DC resistance, because a significant current (up to about 1A) is flowing through it and we don't want too much voltage loss.

The ferrite bead you've selected has a DC resistance of 18mΩ, ie, 0.018Ω which is certainly low enough. So it's certainly suitable. SC

Coming up in Silicon Chip

Smartphone medicine

There are hundreds of smartphone apps used for medical diagnosis and testing, from identifying skin cancers and tracking the blood sugar level of diabetics, to laboratory-style field tests for bacteria and viruses. Dr David Maddison describes many of these emerging technologies, some of which are already in use.

The BWD 216A valve+transistor power supply

BWD was a major Australian electronics manufacturer from 1955 to the 1980s. This power supply, released in the mid 1970s, truly showed off their prowess.

Trailing Edge universal touch and remote control dimmer

This dimmer can be used with a wide variety of lighting including dimmable LEDs. But unlike many so-called universal dimmers, it can also handle multiple incandescent lamps. It's adjusted either by touch (with one or two touch panels) or using an infrared remote control.

USB Mouse & Keyboard Adaptor

These days, most keyboards and mouses are USB only. Many microcontroller projects could benefit from a keyboard or mouse, but you generally don't have a spare USB host interface. This clever project allows you to easily connect a keyboard and/or mouse to just about any micro.

Note: these features are planned or are in preparation and should appear within the next few issues of Silicon Chip.

The February 2019 issue is due on sale in newsagents by Thursday, January 24th. Expect postal delivery of subscription copies in Australia between January 22nd and February 8th.

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Notes & Errata

USB digital and SPI interface board, November 2018: the PCB design is missing a track from pin 10 of IC1 to pin 4 of CON4. It can be added using a short insulated wire link on the underside of the board, or you can use pin 3 of CON3 as MISO/DO instead. We will order PCBs with the corrected pattern (RevB) once the current batch (RevA) has sold out.

GPS-Synched Frequency Reference, October and November 2018: in the circuit diagram (Fig.2) on pages 30 & 31 of the October issue, REG1 should be included inside the red dotted box indicating the oven section. Also, some items are missing from the Parts list on page 33 of the October 2018 issue. Add one 18-pin female header socket and one 4-pin female header socket for connection to the BackPack module (CON1). Constructors may also need three female-female DuPont jumper leads, to cut in half and solder to the GPS module wiring for connection to the header on the main board.

Automatic Reverse Loop Controller, October 2012: in the circuit diagram (Fig.2) on page 40, OPTO2 is incorrectly labelled as a 2N28. It should be 4N28. Also, in the PCB overlay diagram on page 41 (Fig.3) and the parts list on the same page, the 390Ω resistor should be changed to 330Ω to agree with the circuit diagram.

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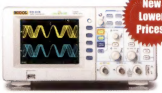

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